Federal Aviation Agency

ADVISORY CIRCULAR

AC NO: AC 00-6

GENERAL

EFFECTIVE: 5/20/65

SUBJECT: AVIATION WEATHER

1. PURPOSE. This circular announces the availability to the public of a new publication, Aviation Weather, (formerly Pilots' Weather Handbook, CAA Technical Manual, No. 104).

2. DESCRIPTION OF THE PUBLICATION. This Handbook is a joint publication of the Federal Aviation Agency's Flight Standards Service and the U. S. Weather Bureau, Department of Commerce. It is designed for pilots or other flight operations personnel and provides an up-to-date and expanded text for pilots and other flight operations personnel whose interest in meteorology is primarily in its application to flying.

3. HOW TO GET THIS PUBLICATION.

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      FAA Advisory Circular AC No. 00-6
      Aviation Weather
      Dated 1965

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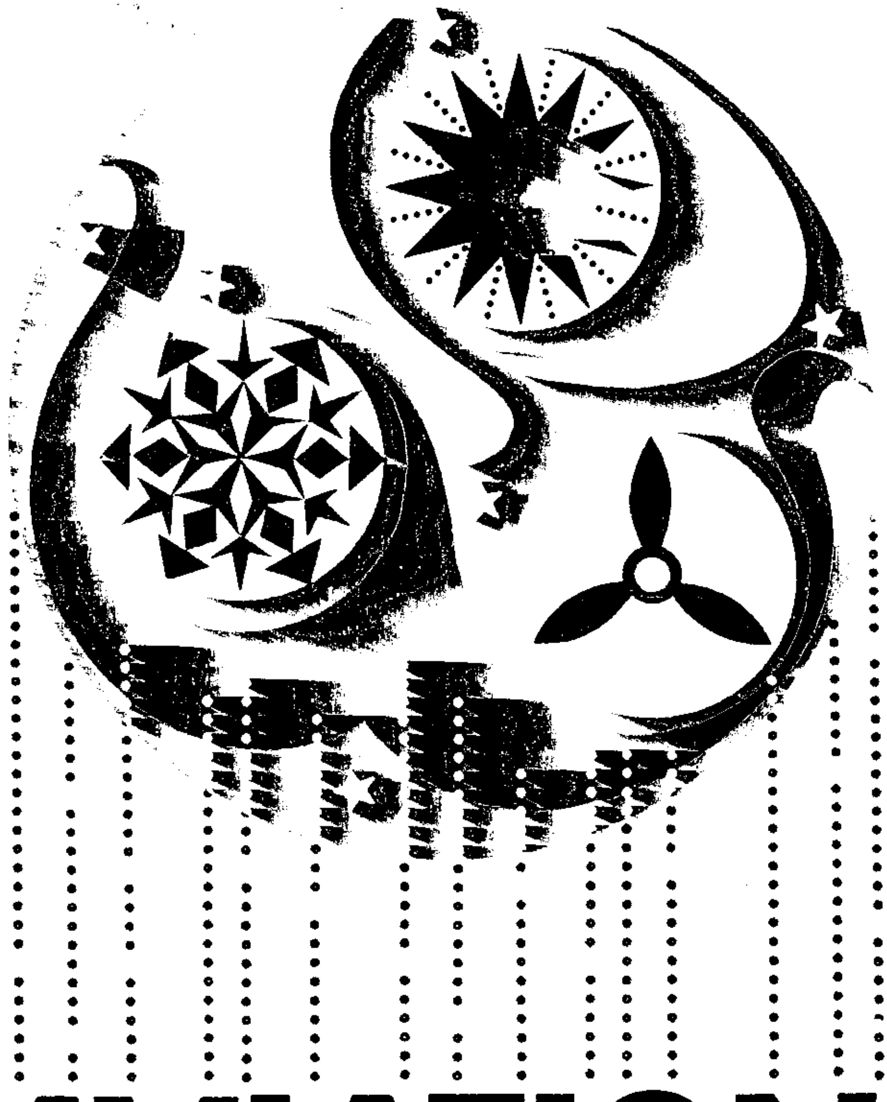
George S. Moore
Director
Flight Standards Service

5-3733



AVIATION WEATHER

Part ONE

SOME LESSONS ON WEATHER

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PART TWO. PRESENT AVIATION WEATHER SERVICES

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FOREWORD

During the past decade, meteorology has undergone a number of important advances. Changes have taken place which again require a revision of the basic weather manual for pilots, last issued in 1954 as the *Pilot's Weather Handbook, CAA Technical Manual No. 104*. The present edition, under the somewhat more general title, *Aviation Weather,* supersedes and replaces *Technical Manual No. 104* and is a joint publication of the Federal Aviation Agency's Flight Standards Service and the Department of Commerce, Weather Bureau.

These advances are reflected in this new publication, *Aviation Weather,* based on earlier civilian and military publications on flying weather. The volume thus provides an up-to-date and expanded text for pilots and others whose interest in meteorology is primarily in its application to flying.

Thunderstorms, blizzards, hail, rain, snow—most of these and many other weather elements affect the lives of every person in some way. The person on the ground can usually take shelter from these elements, or otherwise diminish their effects. For the pilot, weather takes on a much fuller meaning. He must contend with the weather to a far greater degree than persons in most other activities because he must share the airspace with it in one form or another every time he flies. On many occasions, the weather can be a very helpful and enjoyable companion, but oftentimes it is a "monster" to be avoided if possible.

Every pilot needs to know something about the behavior of weather and how various weather conditions affect flying. Just as he does not need to be an aeronautical engineer to fly, neither does he need to become a fully trained meteorologist to cope with weather. The pilot, however, should have a practical understanding of those meteorological principles important to aviation. This is essential to his effective use of current and forecast weather information. Above all, the pilot needs to know how to use his total weather knowledge to best advantage in flying safely and efficiently.

Aviation Weather was prepared in the Weather Bureau by William P. Nash, Meteorologist—pilot, with the assistance of other members of the Weather Bureau. Mr. Nash, who completed his meteorological training at New York University, has had extensive weather forecasting experience and, as a pilot, has experienced many of the flying weather hazards discussed in this publication.

Among the many helpful sources of information available to Mr. Nash was an unpublished manuscript which was prepared for the revision of the Pilot's Weather Handbook by Robert Fennell, Weather Bureau Quality Control Officer, at the beginning of this project. Art work and illustrations were prepared by John J. Smiles, project art director, and his staff in the Graphic Arts and Printing Branch of the Weather Bureau.

Other contributors are the Soaring Society of America, Aircraft Owners and Pilots Association and the Air Transport Association. Many private individuals and groups, people in the Weather Bureau, Federal Aviation Agency, and other government organizations, cooperated and assisted in making this publication possible.

AVIATION WEATHER

For Pilots and Flight Operations Personnel

FEDERAL AVIATION AGENCY
Flight Standards Service

DEPARTMENT OF COMMERCE
Weather Bureau

WASHINGTON, D.C.
1965

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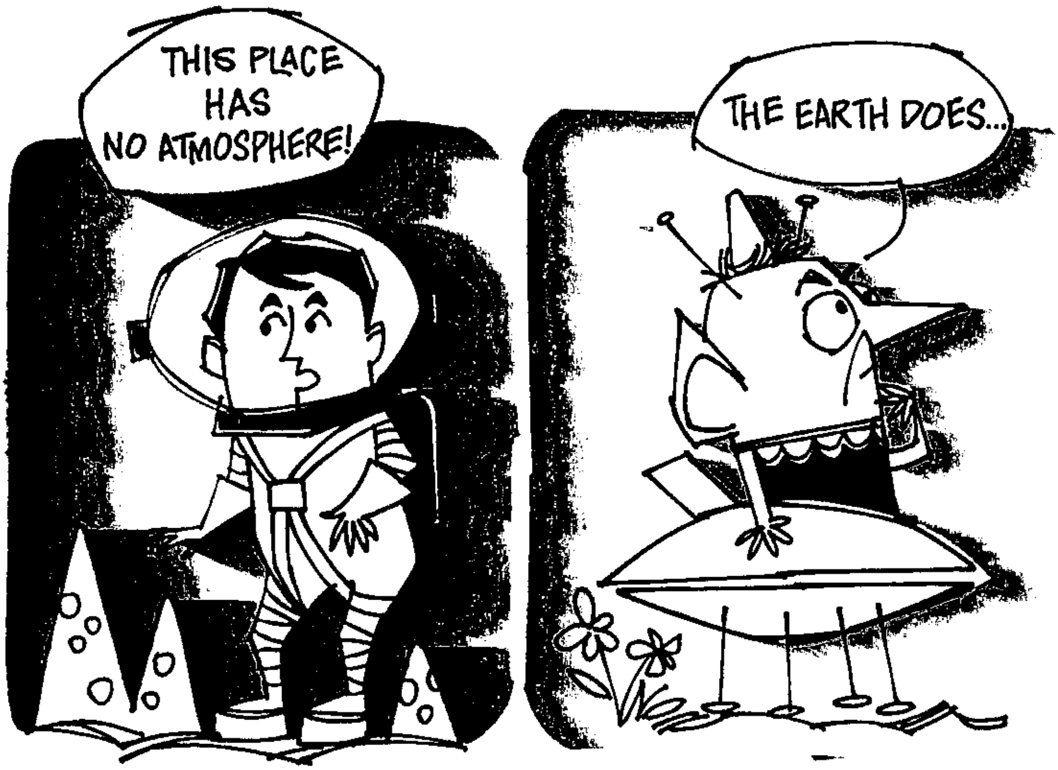


Chapter 1
THE EARTH'S ATMOSPHERE

The atmosphere is the gaseous covering of the earth. If the earth were compared to a baseball, the gaseous covering would be about as thick as the baseball's cover. This envelope of air rotates with the earth. The atmosphere also has a motion relative to the earth's surface, a continuous motion called "circulation." It is created primarily by the large difference between temperatures over the Tropics and those over the Polar Regions, and complicated by uneven heating of land and water areas by the sun. Other factors also influence circulation.

In its vertical dimension the atmosphere is divided into a number of layers, each having certain properties and characteristics. The layer adjacent to the earth is known as the *troposphere.* It varies in depth from an average 55,000 feet over the Equator to 28,000 feet over the poles, with greater depth in summer than in winter. Within this layer, the temperature normally decreases with increasing altitude. An abrupt change in the *rate* of temperature decrease through a thick layer marks the boundary, called the "tropopause," between the troposphere and the stratosphere. Above the stratosphere are the mesosphere and the thermosphere (see fig. 1). Even further subdivisions of the region above the troposphere are made by some atmospheric scientists, according to several sets of criteria.

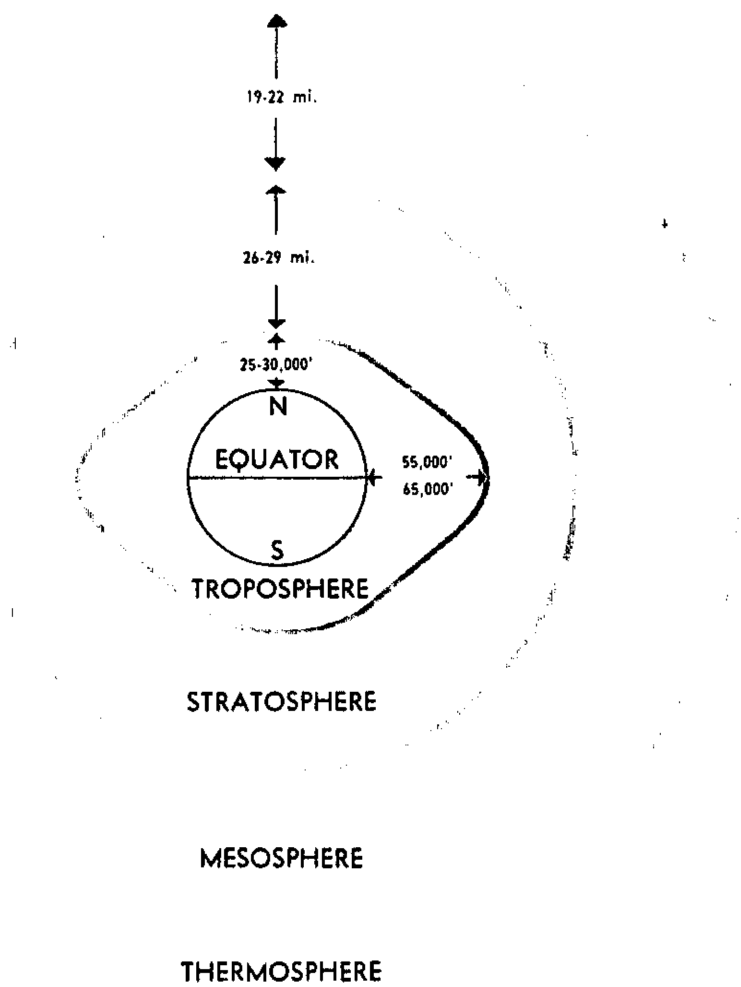


FIGURE 1. The Earth's atmosphere.

This manual deals mostly with the troposphere for these reasons:

1. The troposphere is the most unsettled region of the earth's atmosphere, containing most of the weather affecting aviation.
2. Even though aircraft and space vehicles have carried man much higher than the upper limits of the troposphere, and further progress is being made at a phenomenal rate, most flying is still within this lowest atmospheric layer.

COMPOSITION OF THE ATMOSPHERE

Although extremely light, air has weight and is highly elastic and compressible. It is a mixture of gases. A given volume of pure, dry air contains about 78 percent nitrogen, 21 percent oxygen, and a 1 percent mixture of 10 other gases (see fig. 2). The proportions are about the same in all parts of the world.

The air also contains water vapor which varies

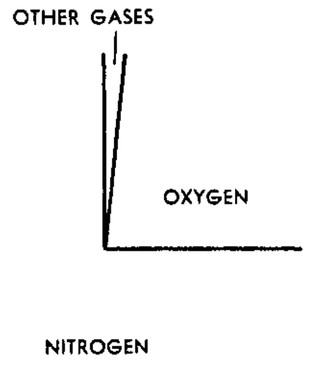


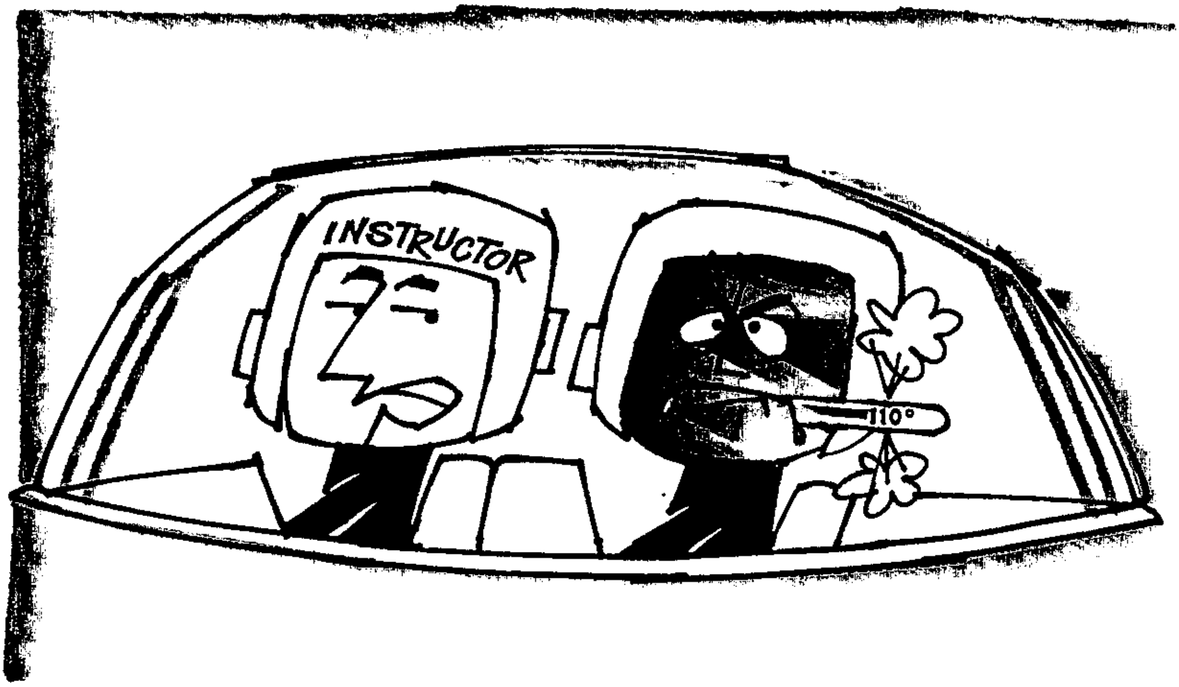
FIGURE 2. Composition of the atmosphere.

in amount from 0 to 5 percent by volume. Water vapor (for ordinary considerations) acts as an independent gas mixed with air.

The atmosphere, even when apparently clear, contains an enormous number of impurities, such as dust particles. When these particles are relatively numerous, they appear as haze and reduce visibility. Distant objects lose their detail when seen through haze and, if they are dark, appear to be viewed through a thin veil of blue.

The atmosphere becomes less dense with altitude, and roughly half of it by weight lies below 18,000 feet. At altitudes where meteorological satellites operate (400 to 600 miles), conditions are similar to those in a high vacuum.

Because the atmosphere contains 21 percent oxygen, the pressure that oxygen exerts is about one-fifth of the total air pressure at any one given level. This is important to pilots because the rate at which the lungs absorb oxygen depends upon the oxygen pressure. The average person is accustomed to absorbing oxygen at a pressure of about 3 pounds per square inch. Oxygen pressure decreases as altitude increases. A pilot continuously gaining altitude or making a prolonged high altitude flight without supplemental oxygen will usually notice a feeling of exhaustion and then an impairment of vision, resulting finally in unconsciousness. Sometimes he may suffer the first effects without realizing it. Therefore, auxiliary oxygen should be used during prolonged flights above 10,000 feet, or when flying above 12,000 feet for even short periods of time. When the atmospheric pressure falls below 3 pounds per square inch (approximately 40,000 feet), even breathing pure oxygen is not sufficient. Since the resulting pressure exerted by pure oxygen is also less than 3 pounds per square inch, a system of pressurization becomes essential. Most military and airline aircraft have pressurized cabins, and they are becoming increasingly common among business and private aircraft.



Chapter 2
TEMPERATURE

Heat is a form of energy. It is also an expression of molecular activity. Temperature is a measurement of heat and thus expresses the degree of molecular activity. Since different substances have different molecular structures, equal amounts of heat applied to equal masses of two different substances will cause one substance to get hotter than the other. This characteristic is expressed by saying that the substances have different heat capacities (specific heat). Every substance has its own unique specific heat. For example, a land surface becomes hotter than a water surface when equal amounts of heat are added to each. The degree of "hotness" or "coldness" of a substance as measured with a thermometer is known as its temperature.

The earth's surface is heated during the day by the sun. Incoming radiation to the earth is called "insolation." Heat is radiated from the earth by outgoing radiation, called "terrestrial radiation." Cooling results at night as terrestrial radiation continues and insolation ceases.

The earth's daily rotation about its axis, its yearly motion about the sun (revolution), the tilt of the earth's axis, and the uneven heating of the earth's surface are the basic causes of seasonal and geographical variations in general weather conditions over the world. The heat energy radiated by the sun is indirectly the major motivating force for all weather phenomena over the earth.

TEMPERATURE MEASUREMENT

Fahrenheit and Celsius (centigrade) are the names given to the two temperature scales important to the pilot. On the Fahrenheit scale, the freezing point is at 32° and the boiling point at 212°—a difference of 180° (see fig. 3). In the Celsius scale, the freezing point is at 0° and the boiling point at 100°—a difference of 100°. The ratio between °F. and °C. is thus 180 to 100, or 9 to 5. This means that a temperature difference of 9° F. is equal to a temperature difference of 5° C. This ratio is used in converting from one scale to another as shown below:

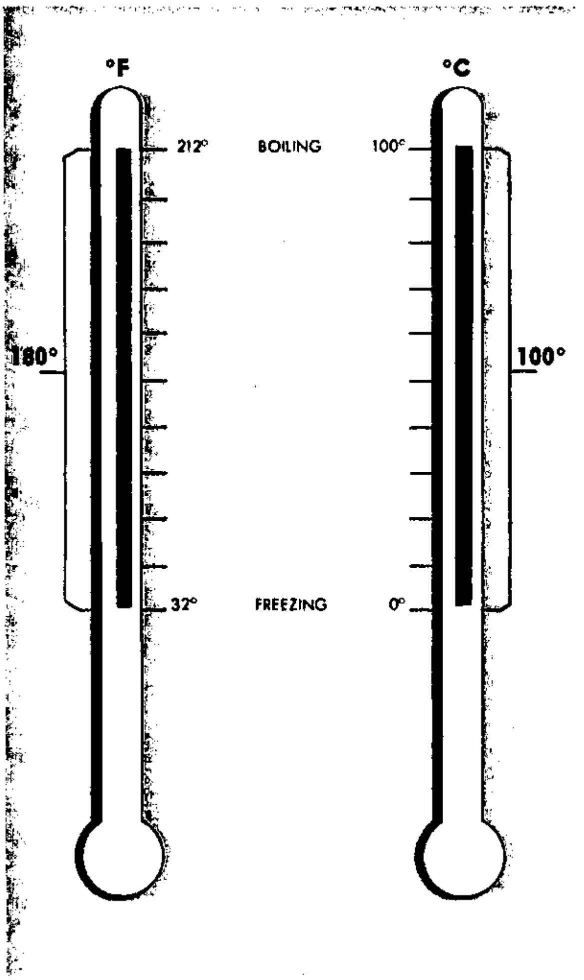


FIGURE 3. Temperature scales.

$$°C = \frac{5}{9}\ (°F + 40) - 40$$

$$°F = \frac{9}{5}\ (°C + 40) - 40$$

Note that the only difference in the conversion from one scale to the other is the 9/5 and the 5/9. This conversion method should be much easier to remember because it is much less complex than earlier methods. Many air navigation computers are marked for direct conversion between Fahrenheit and Celsius.

The temperatures considered in aviation weather are those of the free air. The temperature-measuring elements are exposed in a manner that avoids direct sunlight and minimizes other effects that cause inaccuracies in the readings.

The measurement of outside air temperatures with the typical aircraft thermometer is influenced by several factors (such as radiation, air compression, and friction) which tend to decrease the accuracy of these observations. Such effects may cause the reading to differ from the true free air temperature by as much as 5° F. or more, except where careful engineering has been provided. This should be kept in mind when reading an aircraft thermometer.

All meteorological upper-air temperature measurements are reported in degrees Celsius, but Fahrenheit degrees are used in the United States and some other countries for surface temperatures.

DAILY RANGE OF TEMPERATURE

The range of temperature between night and day varies considerably, both with season and location. The daily range is large near the surface, at barren high-level places, over sand, plowed fields, and rocks, often ranging from 30° to 50° F.; it is much smaller over thick vegetation, and over deep water surfaces it amounts to only about 2° F. There is practically no range of temperature between night and day in the free air 4,000 feet or more above the surface within the troposphere.

The temperature at and near the surface greatly affects allowable gross weights for both takeoff and landing. An aircraft, at the same airport, taking off or landing during night or early morning, generally has more allowable gross weight than it would have in the early afternoon.

TEMPERATURES ALOFT

The pilot is concerned with temperatures aloft in selecting optimum flight altitudes and, to a lesser extent, in determining allowable gross weight.

As his aircraft gains altitude, the pilot notices that the air temperature usually becomes lower and lower. The variation in temperature with altitude is called the lapse rate. It is expressed in degrees per thousand feet. In the troposphere, the temperature, on the average, decreases with altitude at a rate of approximately 2° C. (3½° F.) for each 1,000 feet. Since it is an *average* value, pilots seldom encounter this exact amount of temperature change. The rate of change of temperature with altitude varies over a wide range, depending upon the amount of heat energy reaching and escaping the earth, and upon vertical and horizontal movements of air. Variations can be great from day to day and from one place to another.

Still another variation in the lapse rate is with altitude itself. At a given time and place, for example, the temperature might decrease at a rate of 3° C. per 1,000 feet from the ground to an altitude of 5,000 feet, at a rate of 1° C. per 1,000 feet between 5,000 and 7,000 feet, and at 2° C. per 1,000 feet above 7,000 feet until the tropopause is reached. Many times there is a

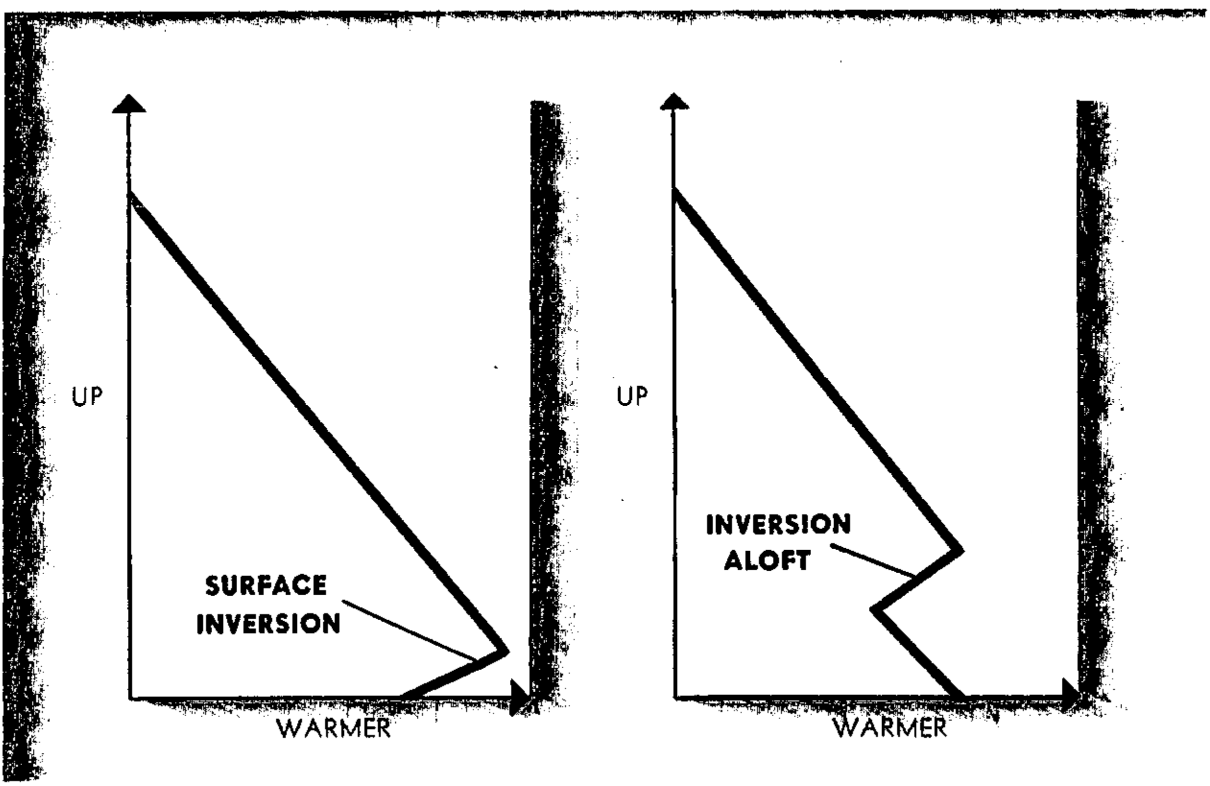


FIGURE 4. Temperature inversions.

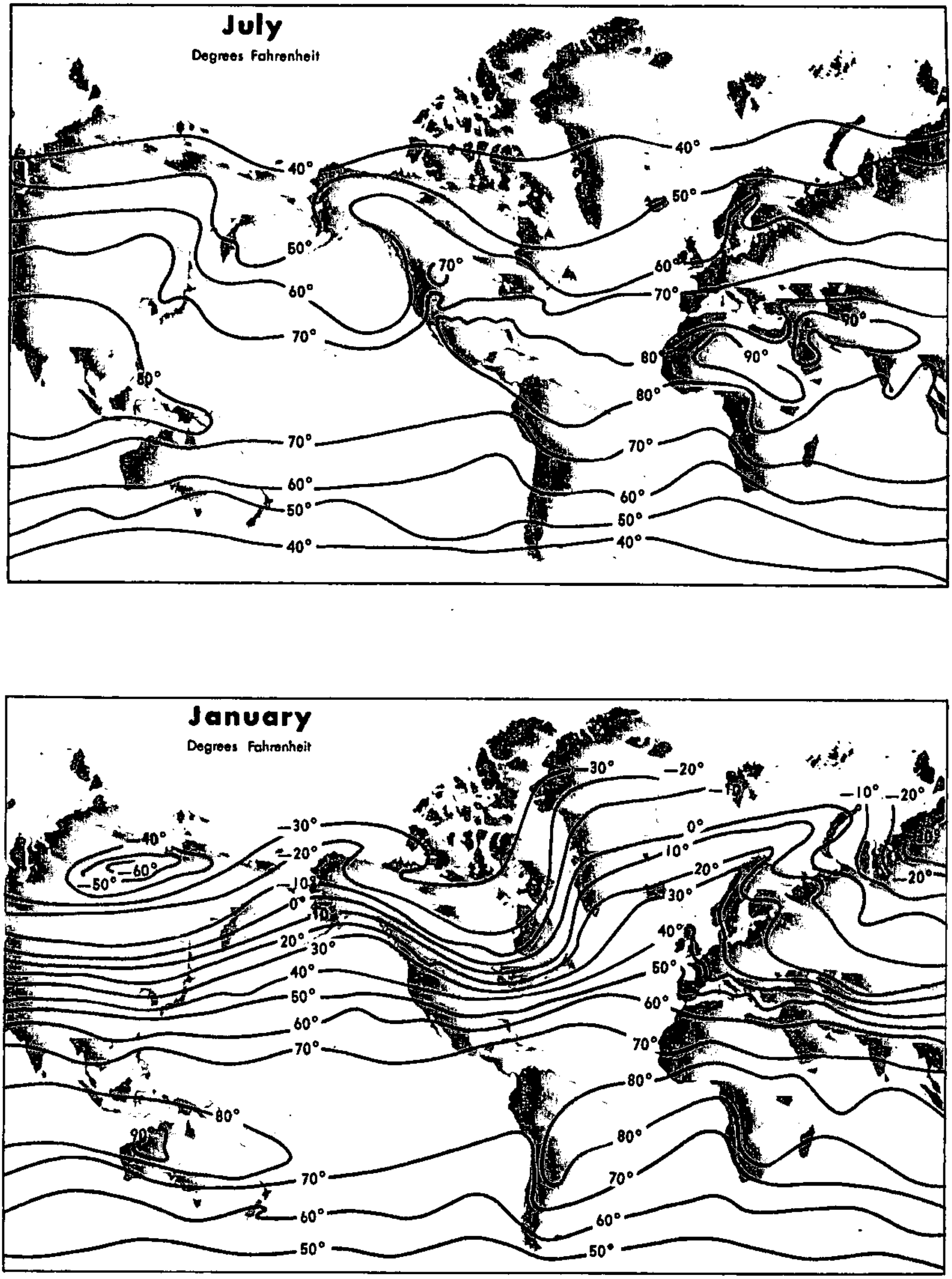


FIGURE 5. World Temperatures (mean).

layer within the troposphere which is characterized by an increase of temperature with altitude rather than a decrease. This situation occurs frequently, but is usually confined to a relatively shallow layer. It is called an "inversion"—the usual decrease in temperature with altitude is inverted.

The most frequent type of inversion over land is that produced immediately above the ground on a clear, relatively still night. The ground loses heat rapidly through terrestrial radiation, cooling the layer of air next to it. The amount of cooling decreases rapidly with altitude, and the temperature of the air a few hundred feet above the ground is affected very little or not at all; thus, the lowest layer of air is colder than the air just above it.

Inversions are often found in association with movement of colder air under warm air or the movement of warm air over cold air. Such inversions are often called frontal inversions. Their formation will be better understood after studying the chapter on fronts.

An inversion sometimes forms as a result of widespread sinking of air (subsidence) within a relatively thick layer aloft, while the air below this layer is essentially unchanged. This sinking air is heated by compression, and it may become warmer than the air below it.

Figure 4 illustrates a ground (surface-based) inversion and an inversion aloft. Restrictions to vision, such as fog, haze, smoke, and low clouds are often found in or below low inversions and in layers through which there is only a small change in temperature. The air in these layers is usually very smooth.

SURFACE TEMPERATURE DISTRIBUTION

The difference in the average temperature conditions over various areas of the earth's surface has been recognized since ancient times. World average temperatures in Fahrenheit for January and July are shown in figure 5.

Chapter 3
ATMOSPHERIC PRESSURE

Atmospheric pressure is the force exerted by the weight of the atmosphere on a unit area. Since air is not a solid object like, for example, an apple, its weight is not easily measured by conventional methods. In spite of this, it was discovered three centuries ago that the atmosphere could be weighed by balancing it against a column of mercury. The device used for this became known as a *barometer* meaning *weight meter.*

THE MERCURIAL BAROMETER

The mercurial barometer consists of an open dish of mercury into which the open end of an evacuated tube is placed (see fig. 6). At stations near sea level, the pressure of the atmosphere causes the mercury to rise, on the average, 29.92 inches up into the evacuated tube. In other words, the weight of the atmosphere, as measured at sea level, is on the average equal

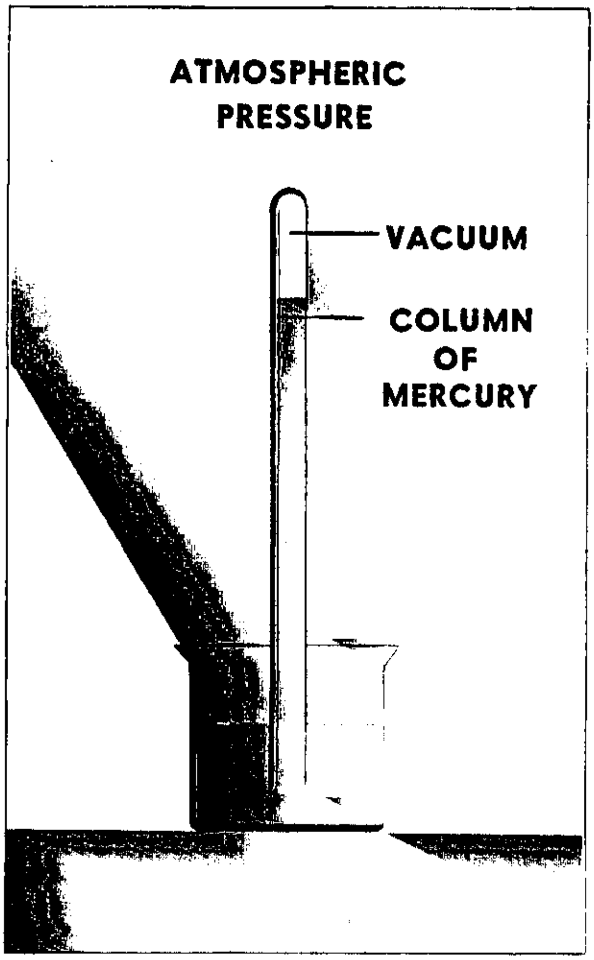


FIGURE 6. The barometer.

to the weight of a column of mercury 29.92 inches high. The atmosphere's weight could be balanced against the weight of any other liquid in a similar way. However, mercury is used because it is one of the heaviest liquids at ordinary temperatures. This permits the weighing instrument to have a manageable size. If water were used instead of mercury, the height of the column balancing the atmosphere's weight at sea level would be about 32 feet.

As altitude increases, the weight of the air above the barometer becomes less and less; so the length of the mercury column required to achieve a balance becomes shorter and shorter. Within the lower few thousand feet of the troposphere, this decrease in the length of the mercury column amounts to roughly 1 inch for each 1,000 feet of altitude.

In the United States, "inches of mercury" as a unit of measurement of atmospheric pressure is popular and is customarily used as a measure of engine manifold pressure. In wide scientific use is a unit of pressure called the "millibar." The standard atmospheric pressure at sea level in millibars is 1013.2, corresponding to 29.92 inches of mercury (units used in altimeter settings), to 760 millimeters of mercury, and to approximately 14.7 pounds per square inch.

THE ANEROID BAROMETER

The essential feature of a typical aneroid barometer (fig. 7) is a cell made of thin metal which is corrugated to make it flexible. The cell is partially evacuated of air so that it will respond more readily to changes of atmospheric pressure. One end of the cell is fixed, while the other end is coupled to a pointer on a dial marked with pressure readings. The coupling magnifies the movement of the free end of the cell. The barograph is an aneroid barometer which is equipped to provide a continuous record of pressure.

STATION PRESSURE AND PRESSURE VARIATIONS

The actual atmospheric pressure at a station is called "station" pressure. This pressure at a given place and time is dependent upon the altitude of the station, the effect of gravity, and the amount of air above the station.

Pressure variations definitely affect flight. The most noticeable effects of decreased pressure due to increased elevation are: higher required true airspeed (TAS) for takeoffs and landings, lower rate of climb, and higher stalling speeds. An average small plane requiring a 1,000 foot run for takeoff at sea level requires almost twice that much for takeoff at Denver, Colo. (5,300 feet above sea level), assuming

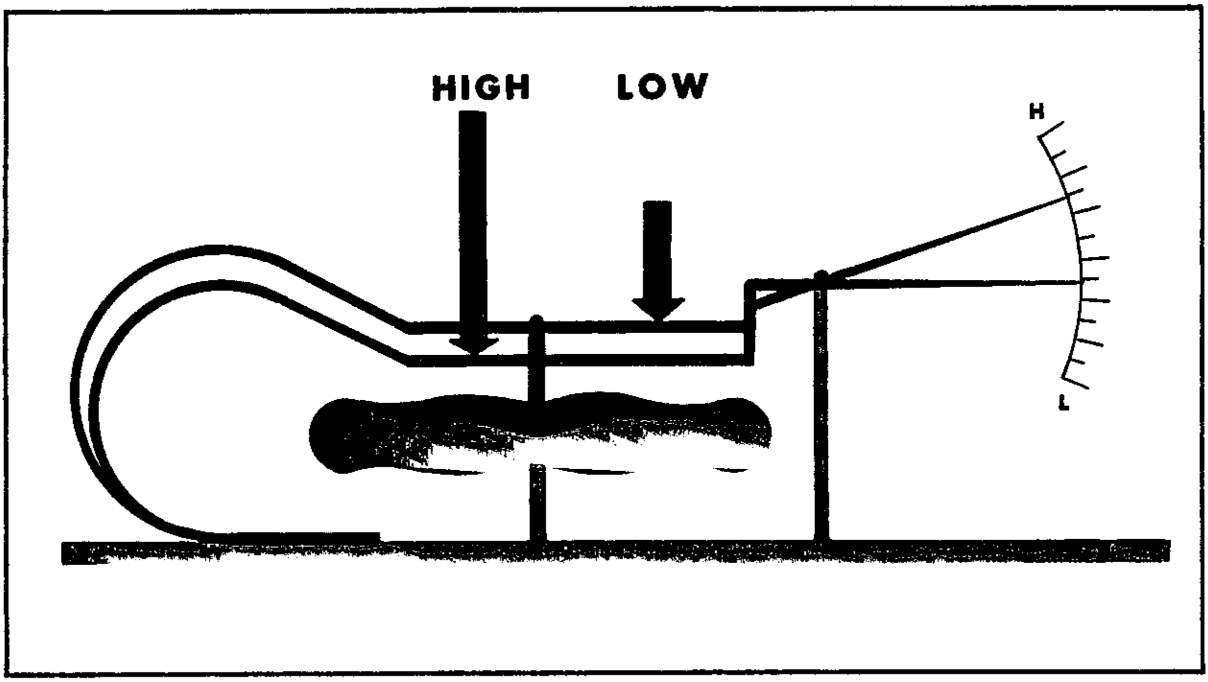


FIGURE 7. The aneroid barometer.

that the surface temperature is the same in both cases (see fig. 8). Similar effects on aircraft are caused by pressure variations with time, but these changes are usually of smaller magnitude.

Pressure varies with time for the three follow-
g reasons:

(1) The movement of pressure systems. The
ge of a well-developed pressure system
is accompanied by a change of 1 inch or
in the atmospheric pressure.

The change in intensity of pressure sys-
such as the deepening or filling of a low
e system.

(3) A daily variation. This variation, which may be thought of as an atmospheric tide, is fairly strong in equatorial latitudes but vanishes above latitude 60°. The pressure is highest from this effect at 10 a.m. and 10 p.m. (local standard time), and lowest at 4 a.m. and 4 p.m. The variation amounts to about 0.04 inch in middle latitudes and to more than 0.15 inch in tropical regions. This is significant because falling pressure may be due only to the daily variations and may not indicate the approach of a storm.

SEA LEVEL PRESSURE

weather stations were located at sea
their individual barometer readings
give a correct picture of surface pressure
ation at a common level. Since stations
at the same elevation, the observed sta-
ssures are adjusted to sea level. If this
done, Denver, for example, would al-
port a lower pressure than New Orleans.
ison of pressure from one station to an-
ould be difficult as a result.

lower troposphere, a difference of 1,000 feet of elevation makes a difference of about 1 inch in the barometer reading. Thus, if an observer at a station located 5,000 feet above sea level found the mercury in the barometer tube to be 25 inches high, he would adjust this reading to 30 inches (25+5) (see fig. 9). The actual reduction of station pressure to sea level is much more complicated, but the example serves to illustrate the principle. Also the observer reports sea level pressure in millibars rather than in inches.

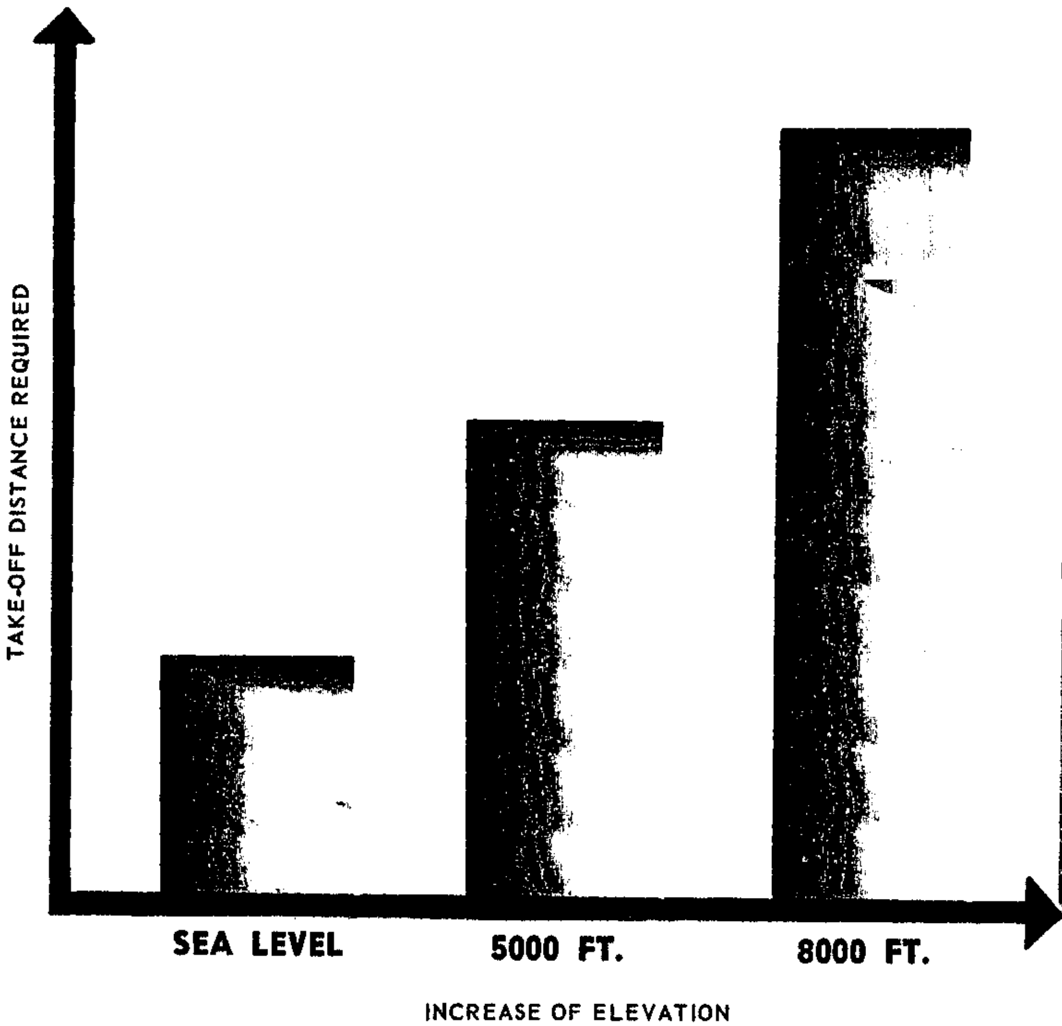


FIGURE 8. Increase in required takeoff run with increasing elevation.

PRESSURE SYSTEMS

The sea level pressure at each station is plotted on a weather chart, and lines of equal pressure (isobars) are drawn at selected intervals (usually 4 millibars). These lines indicate the configuration of pressure systems. The five types of pressure systems are defined as follows:

(1) LOW—A center of low pressure surrounded on all sides by higher pressure.

(2) HIGH—A center of high pres rounded on all sides by lower pressure

(3) COL—The neutral area betw highs and two lows.

(4) TROUGH—An elongated are pressure with the lowest pressure alo called a "trough line," which marks of maximum cyclonic curvature in th

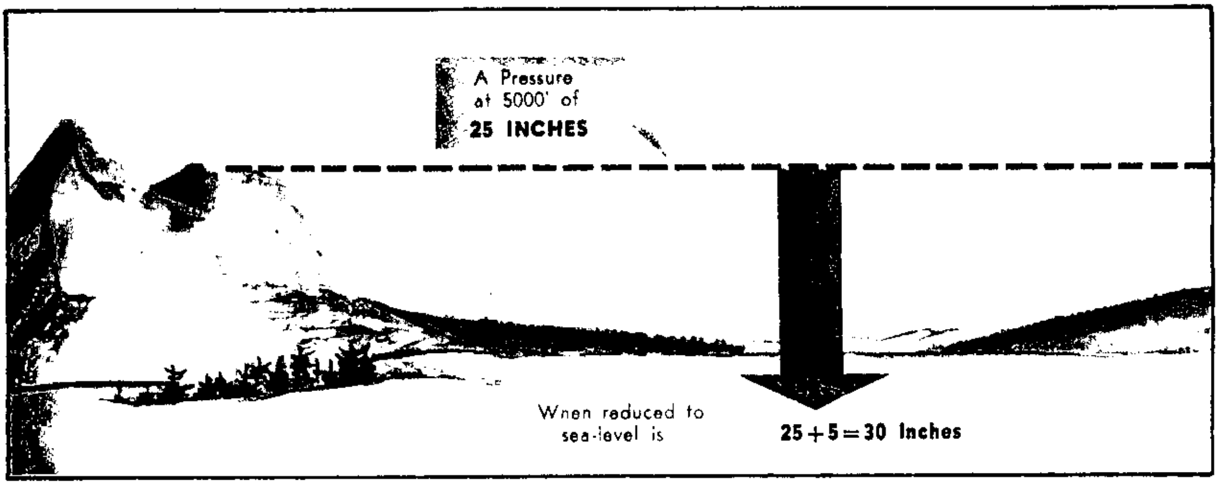


FIGURE 9. Reduction of station pressure to sea level.

(on surface charts) or contours (on upper air charts).

(5) RIDGE—An elongated area of high pressure with the highest pressure along a line, called a "ridge line," which marks the place of maximum anticyclonic curvature in the isobars (on surface charts) or contours (on upper air charts).

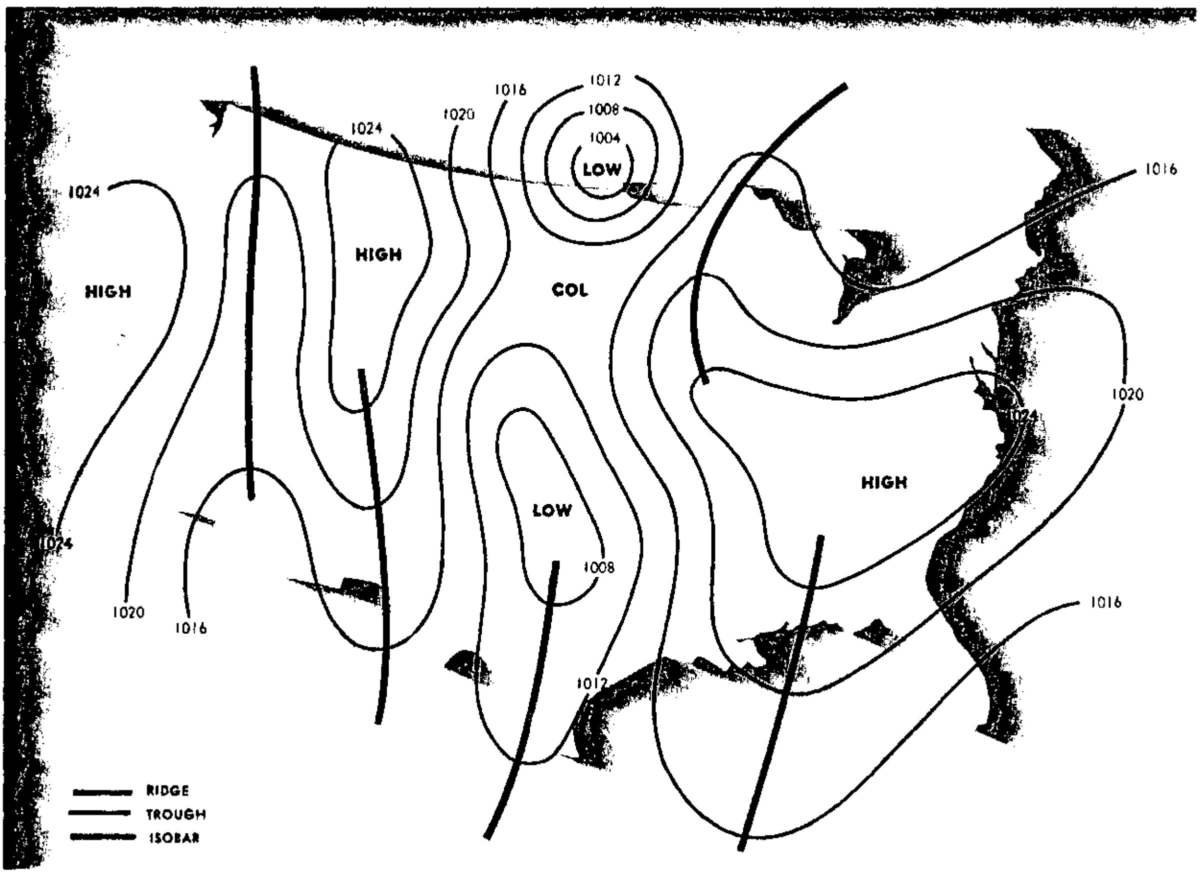


FIGURE 10. Pressure systems.

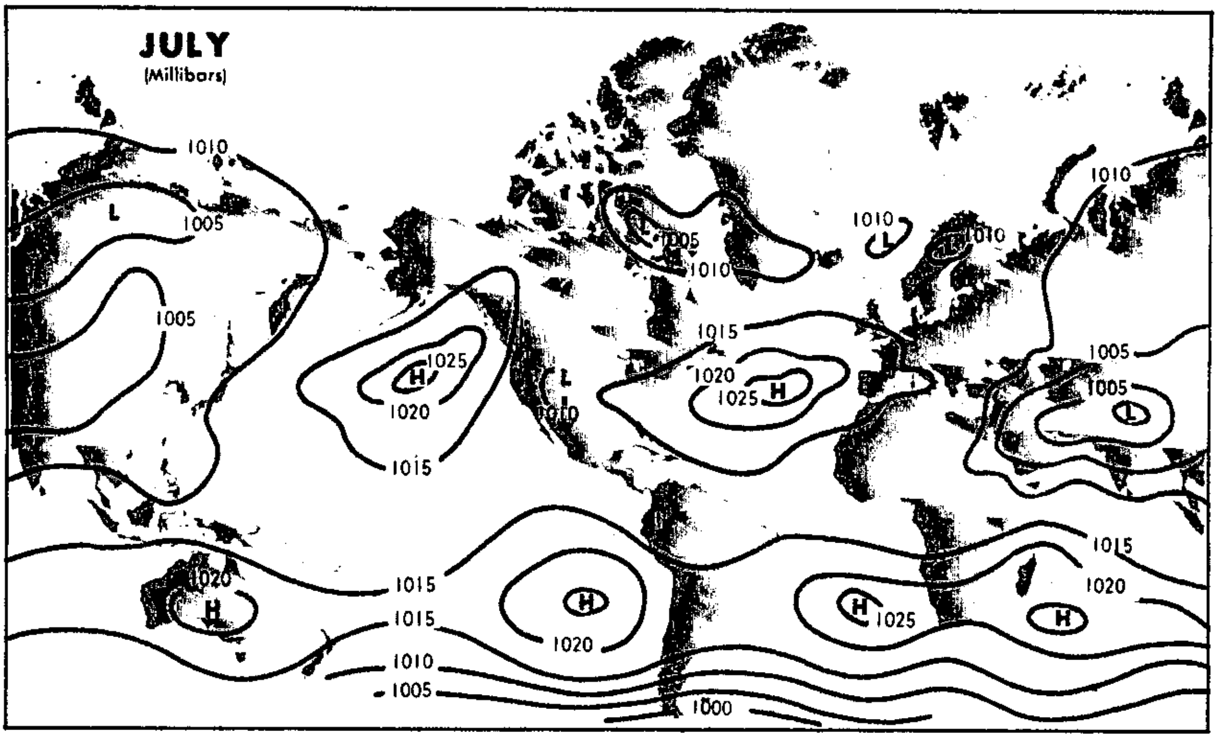


FIGURE 11. Prevailing pressure systems (July).

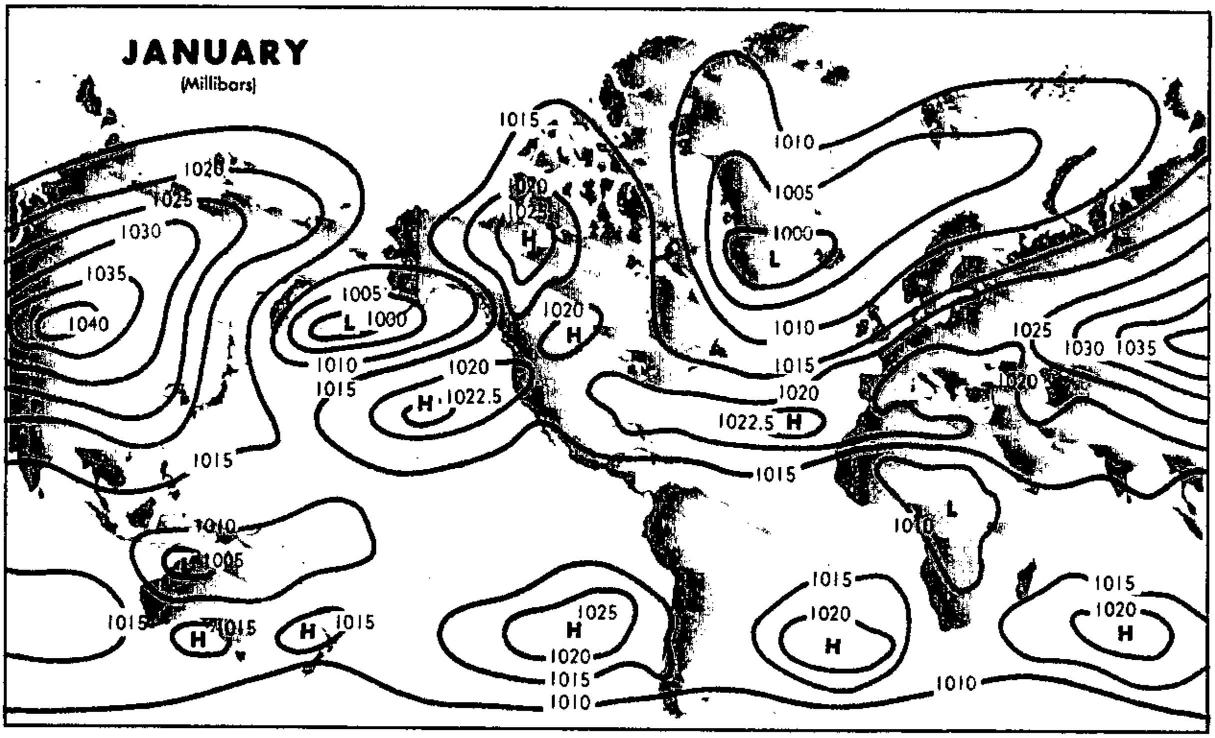


FIGURE 12. Prevailing pressure systems (January).

Examples of pressure systems on a surface chart are shown in figure 10. Note that the isobars have an appearance strikingly similar to the contour lines on a topographic map or aeronautical chart. On upper-air constant-pressure charts, the lines drawn are actually height contours which depict the hills, valleys, and slopes of a constant pressure surface.

A direct relationship exists between pressure systems and the flow of air (wind). Additionally, high pressure areas are typically regions of favorable weather conditions, while lows often are associated with "bad" weather.

Figures 11 and 12 are charts depicting mean pressure systems at sea level over the world in July and in January. Weather charts are treated in greater detail in chapter 16.

ALTIMETERS

Since the barometer gives an indication of the weight of air above it, this instrument carried aloft in an aircraft indicates a reduction of air pressure. An altimeter is an aneroid barometer calibrated to indicate altitude instead of pressure.

The ICAO (International Civil Aviation Organization) Standard Atmosphere, determined by the year-round average of pressure-height-temperature soundings, is the basis for altimeter calibrations. Several relationships between pressure and height, based on the standard atmosphere, are shown in figure 13. The altimeter reading and the actual height are the same only under these conditions: (1) the sea level pressure and temperature are equal to that of the standard atmosphere, and (2) the rate of decrease of temperature with altitude is the same as that specified for the standard atmosphere. Since these standard conditions are seldom, if ever, found, altimeter readings require correction before true altitudes are known. The pilot should remember that altimeter readings are based on an assumed pressure-height relationship, not on actual heights.

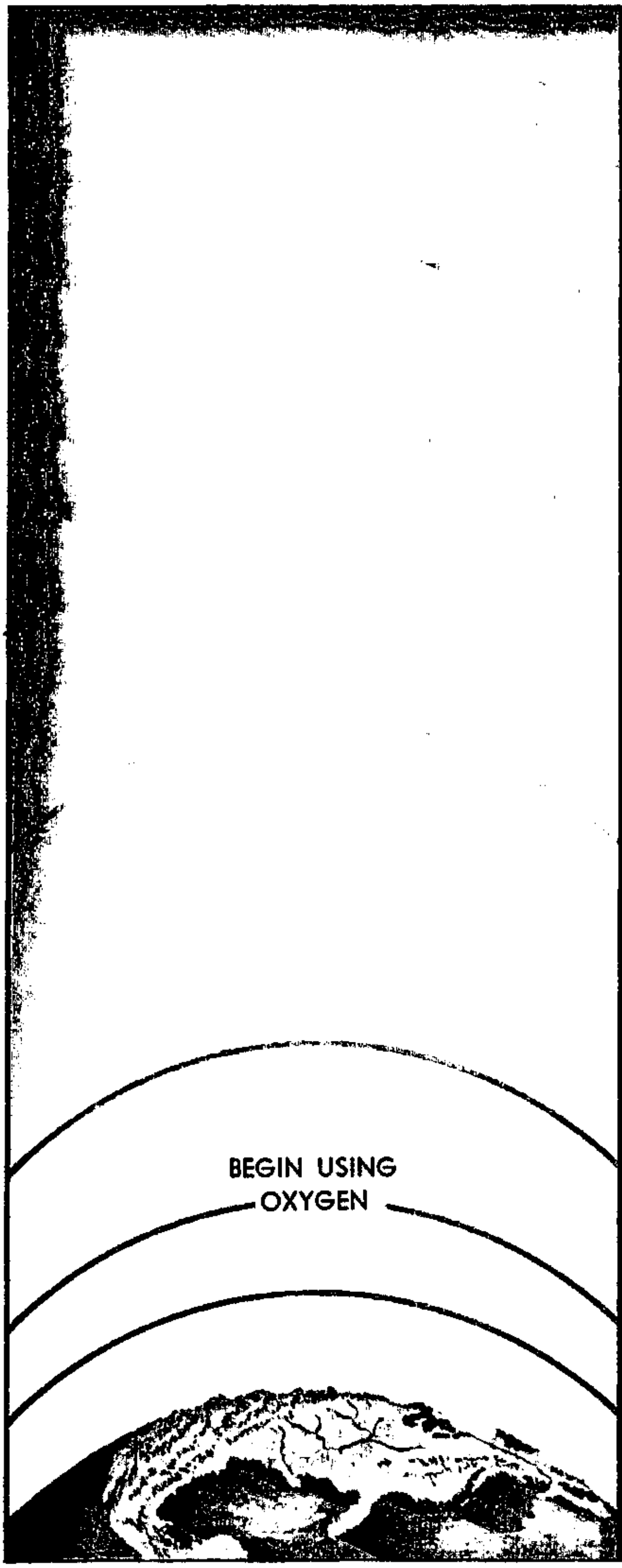
The actual altitude is rarely the same as that which is indicated because of pressure differences along the route (see fig. 14). It is good practice to keep the altimeter adjusted to the current setting for the nearest weather reporting station. Always remember that a change of 0.30 inches in the altimeter setting will result in a change of about 300 feet in the height reading. In extreme cases, this much change in the altimeter setting can occur during a flight of about 200 miles.

Even when sea level pressure does not change along a route of flight, incorrect height indications result from temperature changes. For every 20° F. (11° C.) that the average temperature of the air column between the aircraft and the ground differs from the standard atmosphere, there is a 4 percent error in the indicated altitude. If the air is colder than the standard atmosphere, the aircraft will be lower than the altimeter indicates; if the air is warmer, the aircraft will be higher than the altimeter indicates (see fig. 15). Some pilots find themselves in difficulty when flying on instruments in cold weather because they do not understand this altimeter error and thus do not allow sufficient margin for clearing mountains.

Although subject to errors, the altimeter is still a very useful instrument. The pilot should allow for these errors in flight planning. When the altimeter is adjusted to the landing field altimeter setting, the error due to nonstandard temperature diminishes on descent until, upon landing, the altimeter reads the field altitude.

In flying on the basis of altimeter readings, all heights indicated are above *sea level*, subject of course to the difference and errors discussed above. This sea level reference makes it easy to determine how much clearance is needed to pass safely over mountains or other obstructions, as their heights above sea level are indicated on the aeronautical charts.

The usual procedure is to adjust the altimeter to the local altimeter setting just prior to takeoff. If this setting is not available, the instrument may be set properly by rotating the scale so that the indicated altitude is equal to the elevation of the airport. The "setting" indicated in the small window on the instrument will then be the proper altimeter setting. This can be done only when the aircraft is on the



ALTITUDE (feet)	PRESSURE (inches of mercury)	TEMPERATURE (degrees Celsius)
70,000	1.3	−55.2
50,000	3.4	−56.5
35,000	7.0	−54.0
18,000	14.9	−20.6
10,000	20.6	−4.8
5,000	24.9	5.1
MEAN SEA LEVEL	29.92	15.0 (59°F)

FIGURE 15. The Standard Atmosphere.

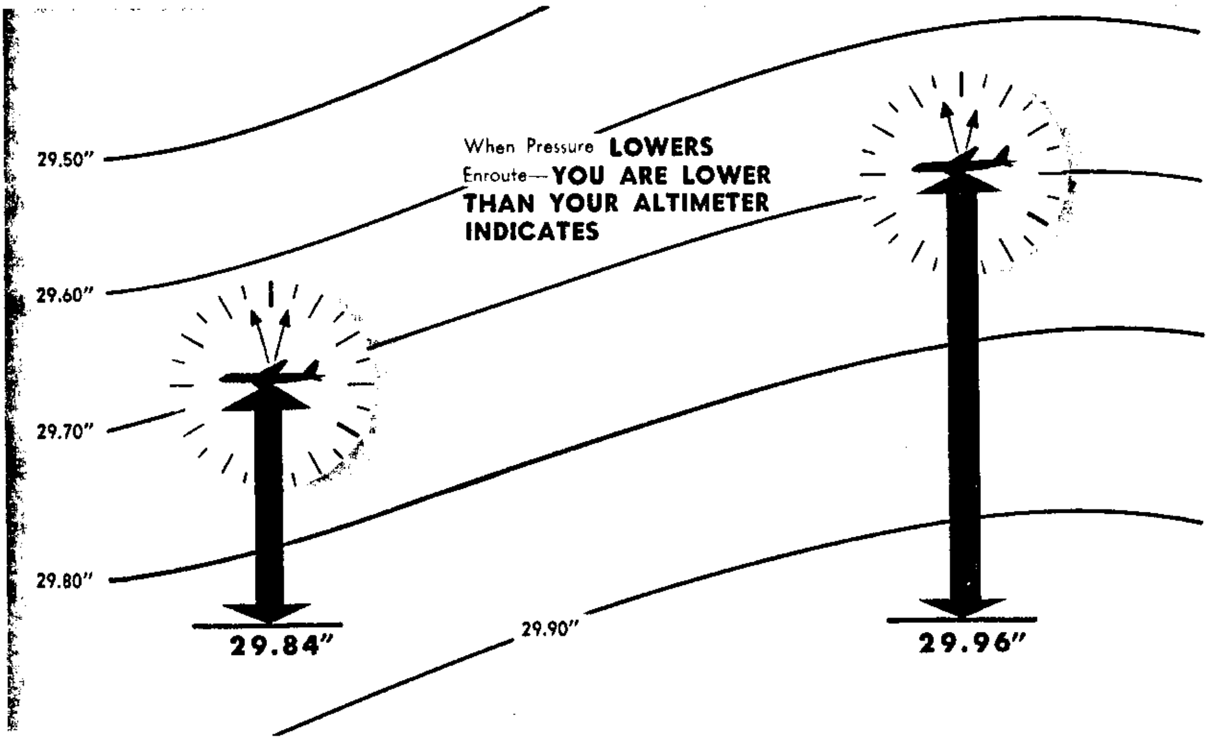


FIGURE 14. Pressure effect on the indicated versus true altitude.

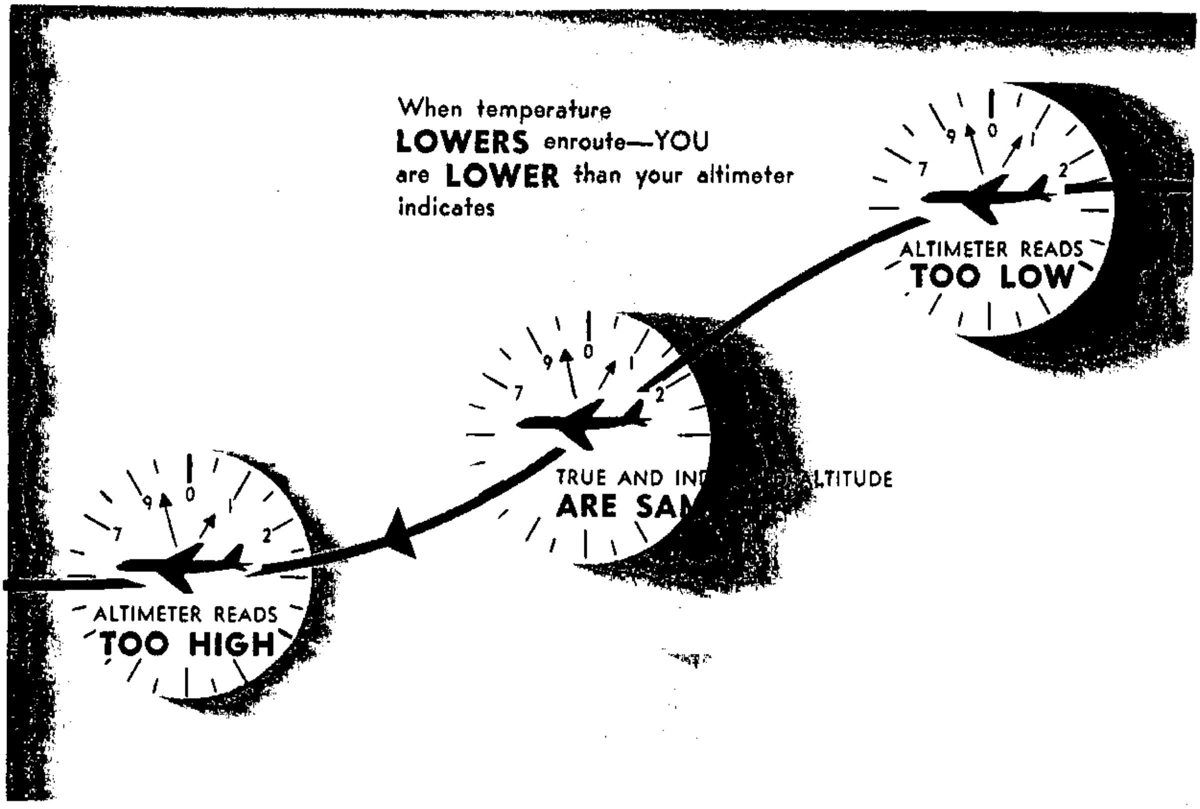
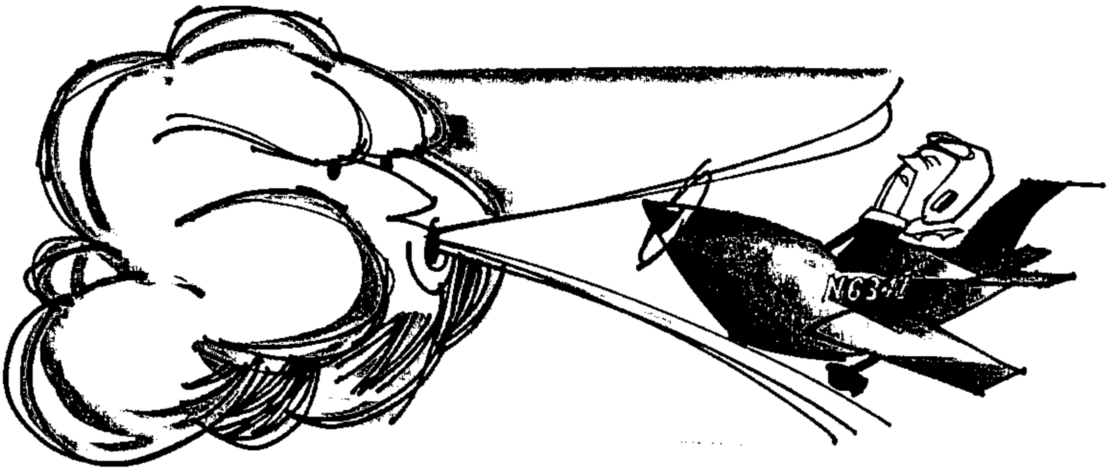


FIGURE 15. Effect of lower than standard and higher than standard temperature on true altitude (without pressure change).

ground. When flying below 18,000 feet, the instrument should be adjusted to the altimeter setting of the nearest ground reporting station. At and above 18,000 feet, all aircraft altimeters are required to be set to the standard atmospheric pressure (29.92 inches). The pilot flying at 18,000 feet or above is required to adjust his altimeter to the setting given by the local ground station when passing through 18,000 feet during a descent for operation below this altitude. (Part 91 of the Federal Aviation Regulations prescribes specific rules governing altimeter setting procedures for operation of aircraft within the United States.)



Chapter 4
WIND

Pressure and temperature variations result in two kinds of motion in the atmosphere: (1) the movement of air in ascending and descending currents (vertical motions), and (2) the horizontal flow of air known as "wind." Both of these motions are of primary interest to the pilot because they affect the flight of aircraft in takeoff, landing, climbing, speed, and direction. They also affect the degree of smoothness of the air and bring about changes in weather which may make a difference between safe flight and disaster.

This chapter deals mostly with the horizontal flow of air. The movement of air in ascending and descending currents is treated to some extent in a number of places throughout the manual but in greatest detail in the chapters on turbulence, thunderstorms, and soaring.

It is difficult to distinguish between cause and effect of wind, pressure, and temperature because of their close interrelationship. Actually, wind affects the very thing that causes it in a never ending struggle to obtain equilibrium—just as the ocean tends to maintain a constant level. Wind occurs because there are horizontal pressure differences in the atmosphere.

But horizontal pressure differences are primarily the result of uneven temperature distribution. On the other hand, wind very definitely affects both the horizontal and vertical distribution of temperature. It also is the main mechanism through which the mass (weight) of the atmosphere is redistributed, thus causing the pressure to change.

As the transportation agency for water vapor, wind has an important effect on the formation of fogs and clouds and on the production of precipitation.

BASIC THEORY OF THE GENERAL CIRCULATION

The term "circulation" used in this discussion refers simply to the movement of air relative to the earth's surface.

Since the atmosphere is fixed to the earth by gravity and rotates with the earth, there would be no circulation if some force or forces did not upset the atmosphere's equilibrium. Also, the pressure exerted by the weight of the atmosphere would be the same over the entire earth (assuming a common reference level such as sea level). But sea level pressure does vary considerably, both with time and location. Pressures also have a tendency to be lower than standard in some areas and higher than standard in others (see figs. 11 and 12). Areas where pressures tend to be relatively high or relatively low change with season. In India, for example, a low pressure area forms over the hot land during the summer months but disappears and reforms over the warmer ocean when the land cools in winter. Balloons and automobile tires burst when overinflated because pressure tends to equalize itself. Air *moves* from the broken balloon or automobile tire to the area surrounding it. In other words, the air moves from an area of high pressure to an area of lower pressure. But why is the pressure of the atmosphere higher in one place than another? The low pres-

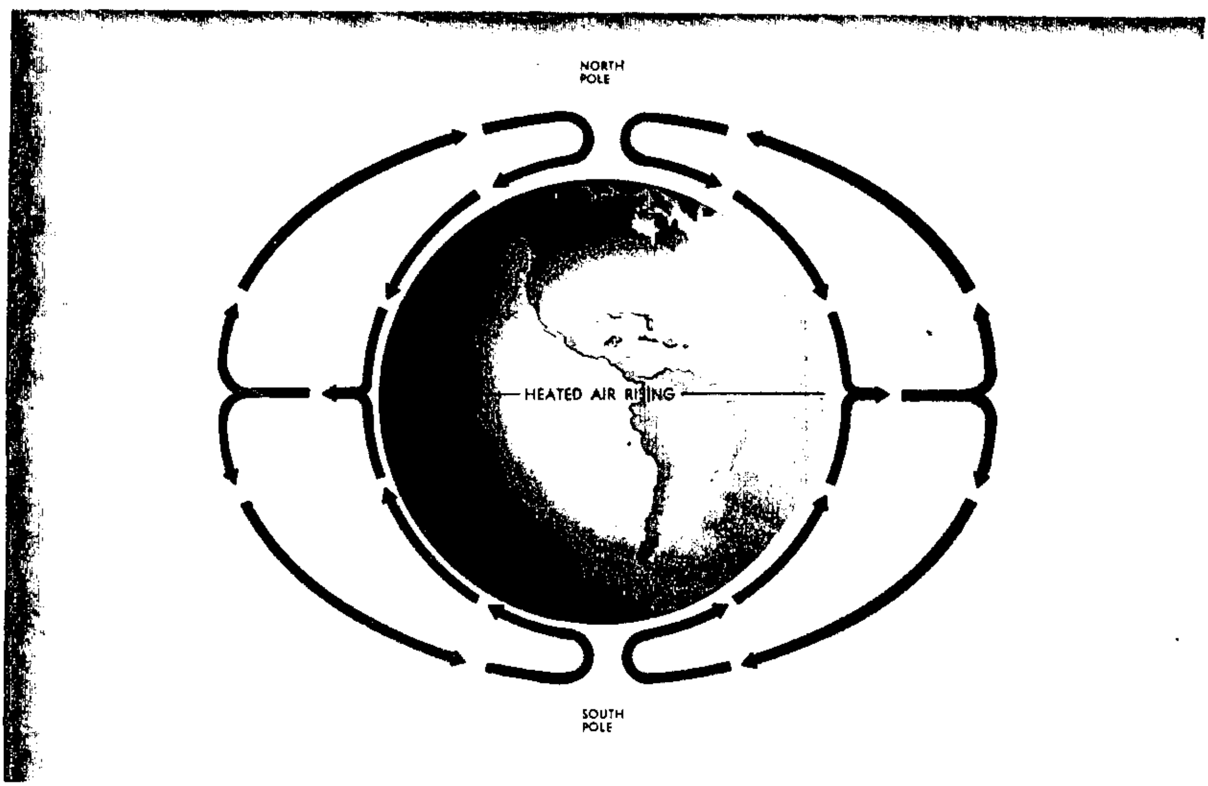


FIGURE 16. Theoretical air movement if the earth did not rotate.

sure area in India in summer is evidence that these differences in pressure are closely related to differences in the amount of heat.

The sun heats the earth's surface unevenly. The most direct rays of the sun strike the earth in the vicinity of the Equator, thus heating equatorial regions much more than the polar regions. In addition, equatorial regions re-radiate to space less heat than is received from the sun, while the reverse is true at the poles. Yet, the equatorial regions do not continue to get hotter and hotter, nor do the polar regions get colder. The only plausible explanation is that heat is transferred from one latitude to another by the actual transport of air.

It perhaps should be pointed out that any explanation of the general circulation is theoretical and as such does not have universal acceptance. However, atmospheric scientists have knowledge of forces which logically must influence the wind circulation. To answer the critics who might ask why such a controversial subject is even included in a weather manual for pilots, it is only natural that one who must routinely consider wind in his flight planning would want some explanation of "why the wind blows."

A popular method of illustrating what is often regarded as the basic cause of air movement is presented in figure 16. Here is theorized what the atmosphere's circulation would be if the earth did not rotate and had an even and uniform surface. As the air near the Equator is heated, it becomes less dense. The heated air rises and flows away, resulting in lower atmospheric pressure than that in the sur-

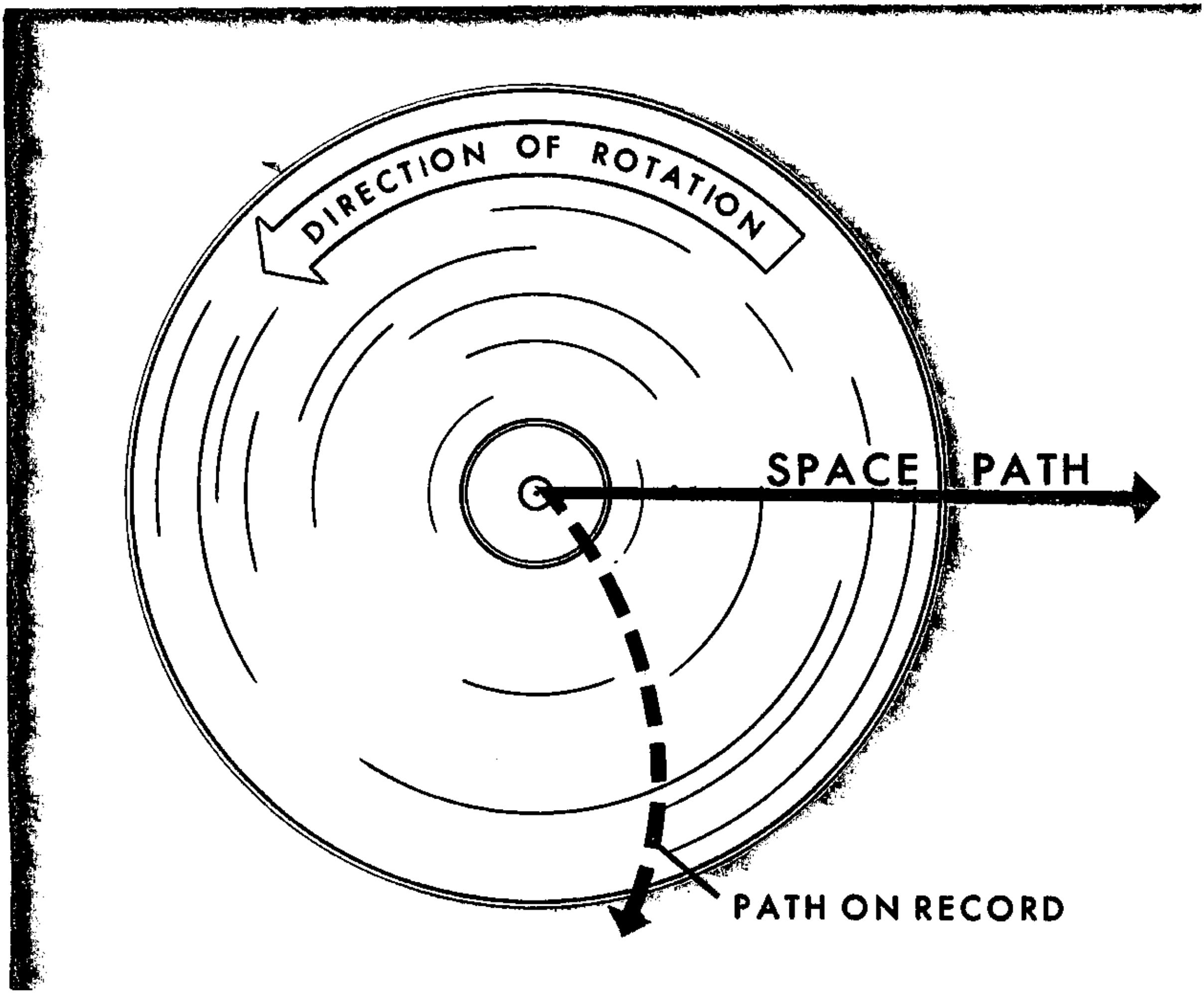


FIGURE 17. Deflective force due to rotation of a horizontal plane.

rounding area where the air is more dense because of its cooler temperature. Thus the air from the north and south moves toward the equatorial low pressure belt (the equatorial trough), forcing the warm air upward. The cooler air in turn becomes warm, is forced to rise, travels aloft toward the poles, and returns along the earth's surface to the Equator in a never-ending process.

Accepting the fact that the earth *does* rotate and its surface is not even and uniform, examine the more important ways in which the simple circulation pattern in figure 16 is modified.

CORIOLIS FORCE

The rotation of the earth brings about an apparent force on the atmosphere which deflects the wind toward the right in the Northern Hemisphere and toward the left in the Southern Hemisphere. This deflective force, called the "Coriolis force," can be illustrated as follows: start rotating the turntable on a phonograph record player; then with the use of a ruler and a piece of chalk, quickly draw a "straight" line from the center to the outside edge of the rotating turntable. To the person drawing the line, the chalk traveled in a straight line. If the turntable is then stopped, it can be seen that the line drawn on it is not straight, but is curved as indicated in figure 17. Similarly, air moving a considerable distance over the earth is deflected because of the spinning of the earth on its axis. In fact, any free-moving body is deflected as it moves over the earth. Viewed from some point in space, the free-moving body would appear to follow a straight line. To one stationed on earth, however, its path would appear to be a curve. Hence the "force" is only apparent, but the deflection is real as far as we on earth are concerned.

With the discussion limited to the Northern Hemisphere, the Coriolis force may be applied to the simplified pattern of circulation (fig. 18). As the air is forced to rise and moves northward from the Equator, it is deflected toward the east; by the time it has traveled about a third of the distance to the pole, it is no longer moving northward, but eastward. This causes the air to pile up in the so-called "horse latitudes" (around 30° north latitude) and produces a high pressure area. Air moving southward out of the horse latitudes is deflected toward the west, producing the northeast "Trade" winds. Wind direction is always stated as the direction *from which* the wind is blowing.

In the polar regions, a similar process is in operation, with the southward moving polar air being deflected toward the west to become an east wind.

Air is forced northward from the high pressure area near 30° N. latitude and is deflected toward the east to become a west wind, thereby producing the so-called "prevailing westerlies" of the middle latitudes. When this air meets the colder polar air, it moves up over the colder air, producing an accumulation of air in the upper latitudes. The cold polar air, as a result, is forced to break out spasmodically in waves which surge toward the Equator, reducing the accumulated pressure. This is called a "polar outbreak" or "cold wave." The boundary zone where the wedge of cold polar air and the warmer air of the prevailing westerlies come into contact is called the "polar front." ("Fronts" is the subject of ch. 10.)

PRESSURE GRADIENT FORCE

As previously indicated, air tends to flow from high pressure to low pressure. This flow would be direct if this were the only force operating. Wind speed increases as the pressure gradient (change of pressure with distance) increases. Spacing of isobars on surface weather charts and contours on constant-pressure charts, therefore, gives a rough indication of wind speeds. When they are close together, the pressure gradient is strong and wind speeds are high.

The deflection of air as a result of the Coriolis force tends to counterbalance the horizontal pressure gradient force. There is a tendency, therefore, for air to flow parallel to isobars and contours rather than directly from high pressure to low pressure (illustrated in fig. 19). Assume that straight parallel isobars are running in a west-east direction with low pressure to the north. The pressure gradient force starts the air moving northward from high to low pres-

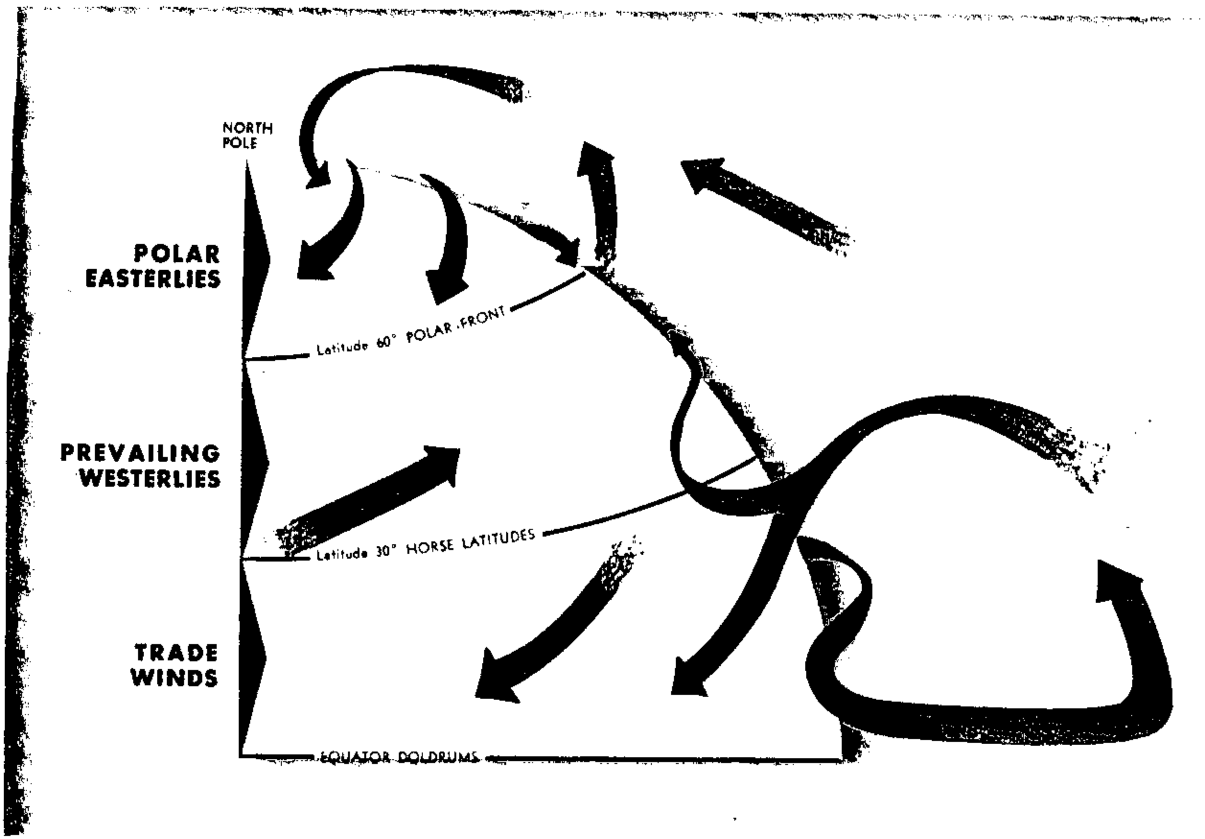


FIGURE 18. The effect of the Coriolis force.

sure, but at the same time, the Coriolis force begins to push the air particles to the right of their path, or toward the south. Finally, the wind is blowing parallel to the isobars and toward the east. When the air is blowing parallel to the straight isobars, the Coriolis force is just balanced by the pressure gradient force.

FRICTION

Friction tends to retard the air movement. Since the Coriolis force varies with the speed of the wind, a reduction in the wind speed by friction means a reduction in the Coriolis force. This results in a momentary disruption of the balance. When the new balance, including friction, is reached, the air blows at an angle across the isobars from high pressure to low pressure. This angle varies from 10° over the oceans to as much as 45° or more over rugged terrain. Frictional effects on the air are greatest near the ground, but the effects are also carried aloft by ascending currents. Surface friction is effective in slowing down the wind up to about 1,500 to 2,000 feet above the ground. Above this level, the effect of friction decreases rapidly and may be considered negligible for all practical purposes. Therefore, air about 2,000 feet or more above the ground usually tends to flow parallel to the isobars.

CENTRIFUGAL FORCE

Isobars and contours are curved around pressure systems. This curvature creates centrifugal force on the movement of air, causing a tendency for it to flow outward from the center of these systems. The effects of this force are to increase the speed of wind in high pressure areas and decrease it in low pressure areas. Other forces in operation, however, usually more than compensate for this effect, since the wind near high pressure centers is usually light and the wind near low pressure centers typically

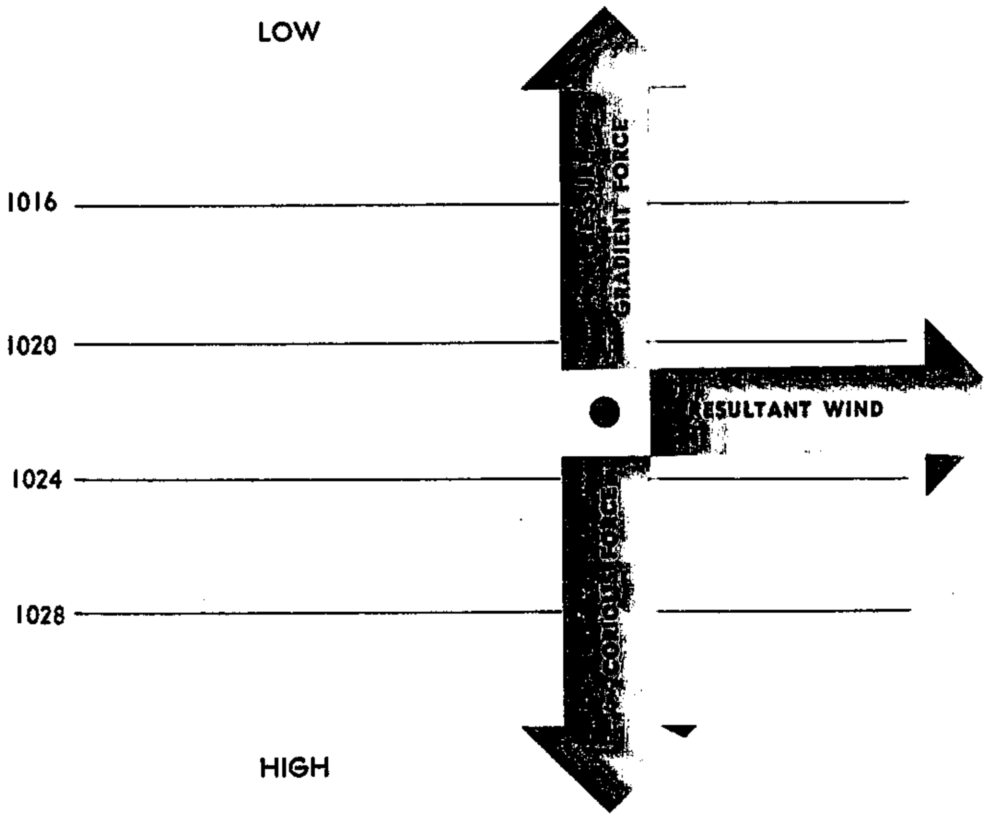


FIGURE 19. The effect of the Coriolis force on the direction of wind flow in relation to isobars.

strong. The strength of the centrifugal force increases with wind speed and decreases as the radius of curvature increases.

GRAVITY

The force of gravity pulls the air downward and produces a density distribution so that the more dense air lies below the lighter air.

OTHER EFFECTS

In the discussion of the general circulation, the earth thus far has been considered as a uniform, smooth globe. This circulation is complicated considerably by the irregular distribution of oceans and continents, the relative effectiveness of different surfaces in transferring heat to the atmosphere, irregular terrain, the daily variation in temperature, the seasonal changes, and many other factors. These factors together with the distribution of solar radiation and the rotation of the earth, lead to the establishment of semipermanent regions of high and low pressure which control the general atmospheric movements in their regions. Refer to figures 11 and 12 for the normal positions in July and January of these principal high and low pressure areas.

These semipermanent highs and lows are important to our basic understanding of the atmosphere's circulation and have some significance to the pilot in his day-to-day flight planning. Of far greater significance, however, are the moving lows (migrating cyclones) and highs (migrating anticyclones) which are associated with the rapid changes in weather so characteristic of the middle latitudes.

LARGE WIND SYSTEMS

CYCLONES AND ANTICYCLONES

Persons living in the temperate zone and farther north know that their weather is changing almost constantly with the alternate passage of cyclones (low pressure systems) and anticyclones (high pressure systems). These migrating systems, on the average, move from west to east with the prevailing westerly winds. They are accompanied by wind shifts and, with some exceptions, large and rapid changes in temperature and broad moving areas of precipitation. Migrating cyclones and anticyclones furnish the most important means through which heat is exchanged between high and low latitudes.

Cyclones are usually a few hundred miles in diameter. Anticyclones are generally larger and often more elongated, the longer axis extending for 2,000 miles or more in some cases.

Isobars are curved in cyclones and anticyclones, but the wind follows the isobars (excluding the friction effect below about 2,000 feet). Figures 20 and 21 illustrate the flow of air around cyclones and anticyclones. In the Northern Hemisphere, air flows counterclockwise around cyclones (low pressure systems) and clockwise around anticyclones (high pressure systems), and a person with his back to the wind has low pressure on his left; the opposite is true in the Southern Hemisphere where the

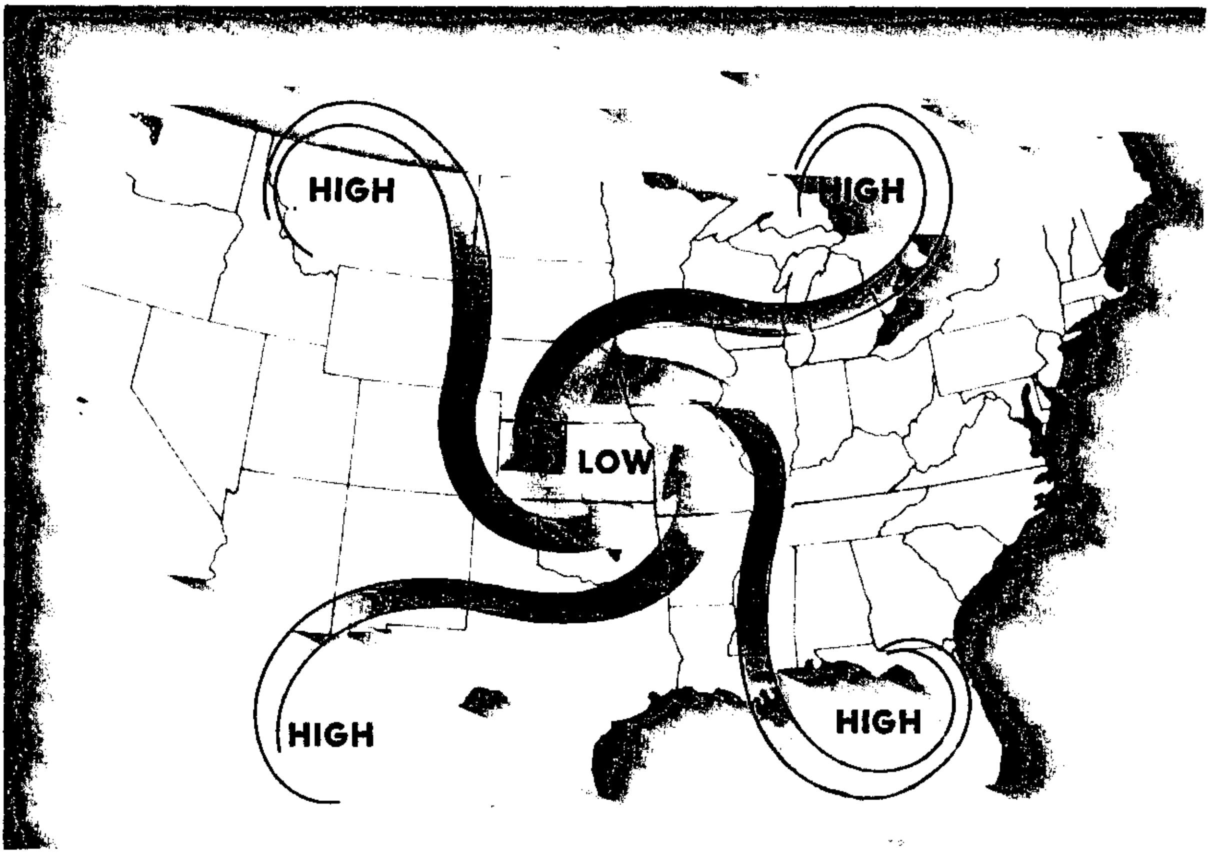


FIGURE 20. Flow of air around pressure areas at the surface.

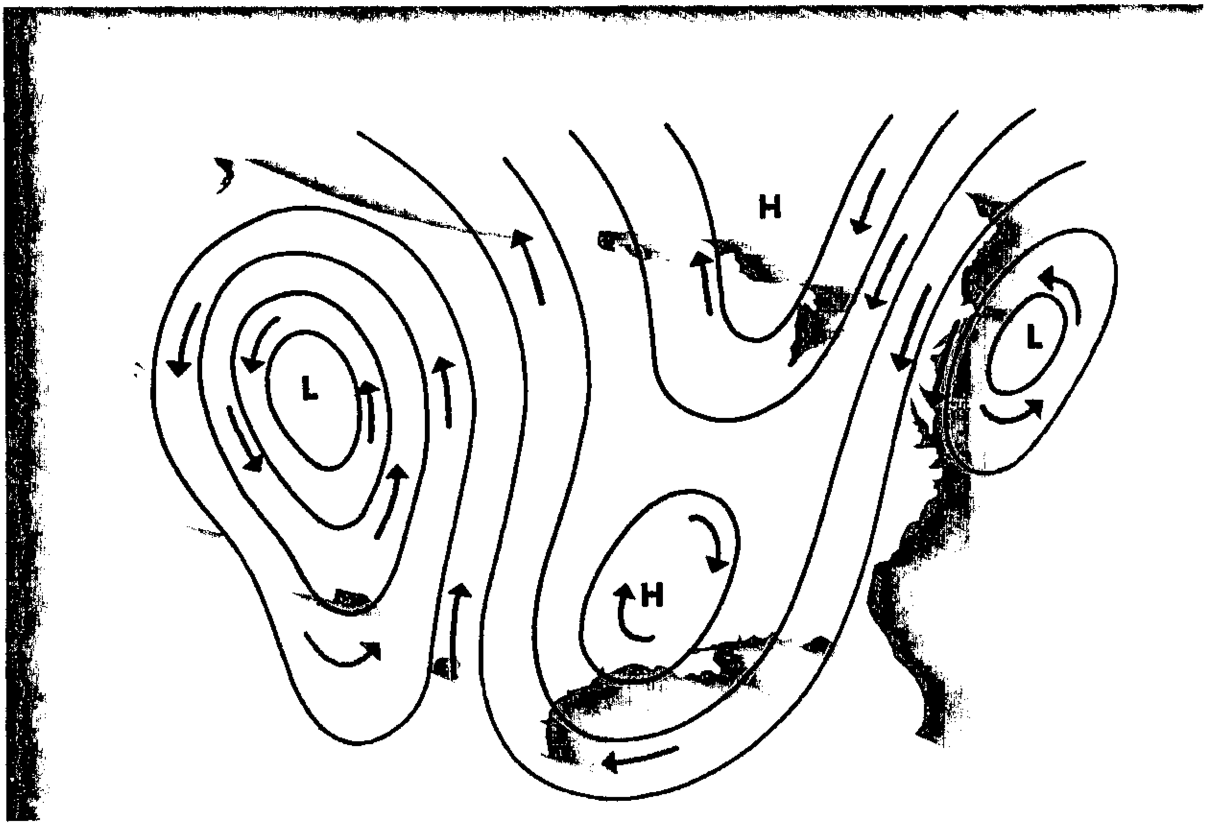


FIGURE 21. Flow of air around pressure areas above the frictional layer.

air flow around cyclones is clockwise, the flow around anticyclones is counterclockwise, and a person with his back to the wind has high pressure on his left.

Wind speeds tend to be considerably greater in cyclones than in anticyclones, but there are notable exceptions, especially in some geographical areas. For example, polar outbreaks are accompanied by rapidly *rising* pressure and *strong* winds.

HURRICANES

The extremely low pressure, very strong winds, torrential rains, and other characteristics of the hurricane make it adaptable to discussion in a number of chapters in this manual. Its treatment in detail is reserved for the chapter on tropical weather (ch. 21) because hurricanes are born in the Tropics.

JET STREAMS

A discussion of very large-scale wind systems would be incomplete without some mention of the "jet stream," the high-speed wind belt found at high altitudes. Chapter 19 deals exclusively with high altitude weather, and discussion of the jet stream is reserved for that chapter.

LOCAL WINDS

Superimposed on the general wind systems are local wind systems created by mountains, valleys, and water masses. These local systems usually cause significant changes in the weather of the area. The term "local" in the case of wind systems is applicable to areas of about one-half of an average-size State to areas roughly the size of two average States.

LAND AND SEA BREEZES

Since temperatures of land masses rise and fall more rapidly than water surfaces through radiation, the land is warmer than the sea during the day and colder at night. This difference in temperature is more noticeable during the summer months and at times when there is little horizontal transport of air in the low levels (the general wind circulation is light). In coastal areas, this difference of temperature between the land and water produces a corresponding difference in pressure (pressure gradient); during the day, the pressure over the warm land becomes lower than that over the colder water. The colder air over the water moves toward the lower pressure, forcing the warm air over land upward. The resulting onshore wind is called a "sea breeze." The process is much like that of the simplified general circulation pattern shown in figure 16, but is of much smaller scale.

At night, the circulation is reversed so that the air movement is from land to sea, producing an offshore wind called the "land breeze." The sea breezes are usually stronger than the land breezes, but they seldom penetrate far inland. Both land and sea breezes (illustrated in fig. 22) are shallow in depth.

The possible existence of a land breeze (at night) or a sea breeze (during the day) should be considered when landing at airports adjacent to large lakes and oceans. Sea breezes of 15 to 20 knots are not uncommon.

MOUNTAIN AND VALLEY WINDS

In the daytime, air next to a mountain slope is heated by contact with the ground as it receives radiation from the sun. This air usually becomes warmer than air at the same altitude but farther from the slope. Colder, denser air in the surroundings settles downward and forces the

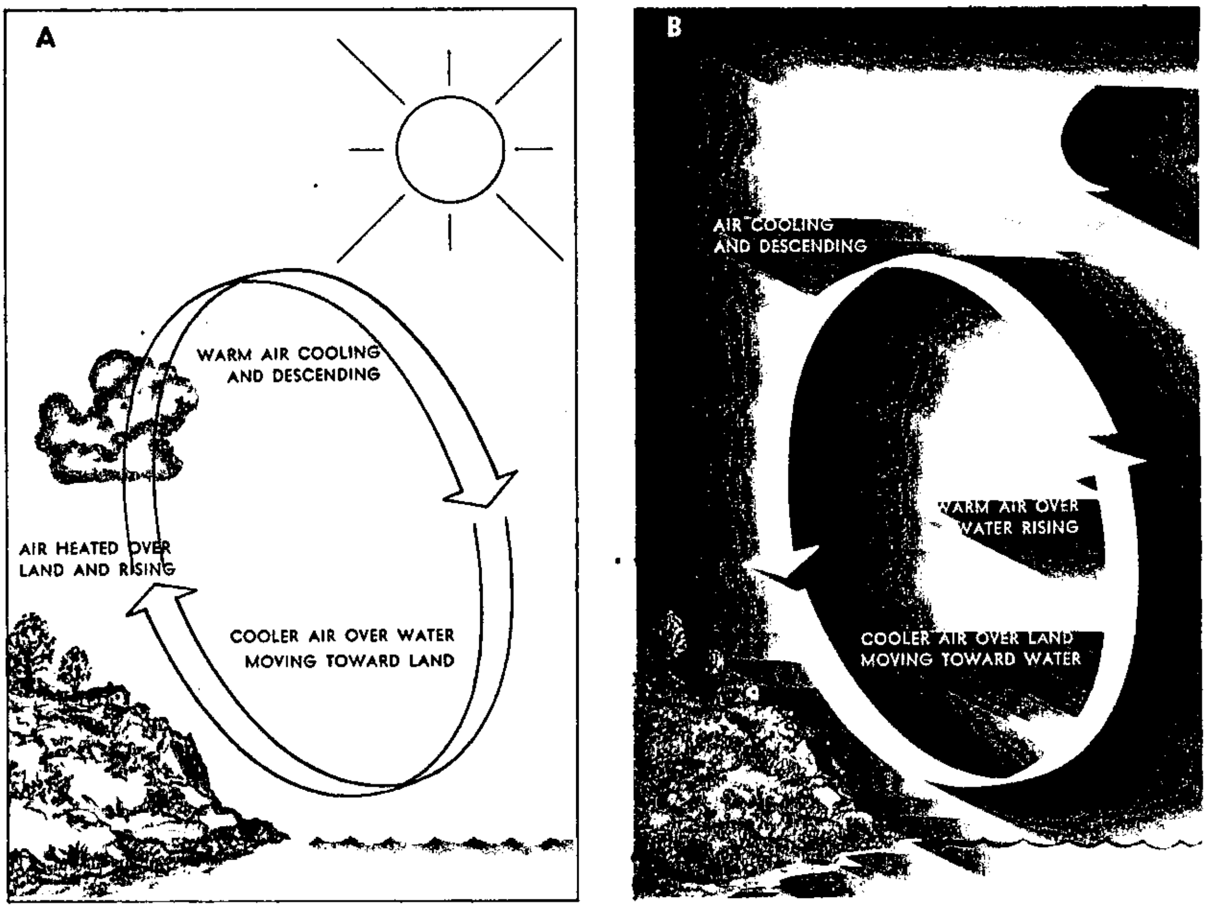


FIGURE 22. Land and sea breezes.

warmer air near the ground up the mountain, producing the "valley wind," so called because the air seems to be flowing up out of the valley.

At night, the air in contact with the mountain slope is cooled by outgoing radiation and becomes heavier (denser) than the surrounding air. It sinks along the slope, producing the "mountain breeze," which acts like water flowing down the canyons. Mountain breezes are usually stronger than valley winds, especially in winter when speeds in excess of 50 knots may be attained by the down-rushing wind.

KATABATIC WINDS

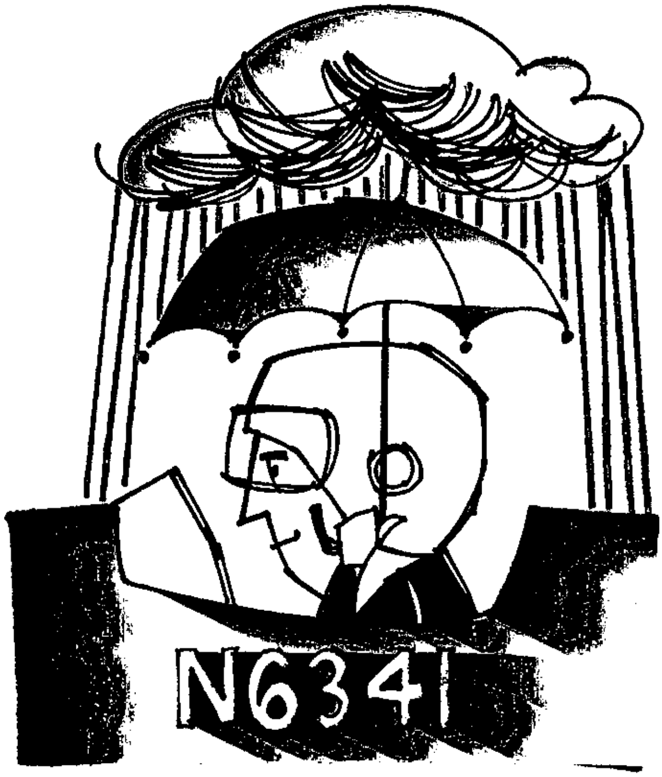
A "katabatic wind" is any wind blowing down an incline. The mountain breeze, therefore, is a type of katabatic wind. If the downslope wind is warm relative to the air in the valley or plain below, it is called a "foehn"; if the downslope wind is cold, it is called either a "fall wind" or a "gravity wind."

Various types of katabatic winds are found in the western United States. The foehn wind located along the eastern slopes of the Rockies is called a "chinook." The air is heated as its moisture is condensed during the ascent on the windward (western) slopes and then is heated even more by compression as it flows downhill from the high elevations. Following the arrival of a chinook wind, the temperature at a weather station near the base of a mountain may rise as much as 30° F. in a few minutes. The foehn wind in southern California, known as the "Santa Ana," attains very high speeds.

Death Valley is very hot and dry partly because all winds which reach that area are downslope winds.

Fall winds are found in very cold plateau regions. Because of its heaviness, the cold air flows downhill under the influence of gravity, resulting in a shallow wind which sometimes attains high speeds. These winds usually affect a rather large area and may occur either during the day or night. However, fall winds are usually stronger at night because radiational cooling of the ground adds to the air's coldness.

In southeastern Alaska, the fall wind is known as the "Taku," or sometimes as the "bora." Specifically, a "bora" is a wind so cold at its source that, even after being heated by compression during the descent, it arrives in the valley at a lower temperature than that of the air it is replacing.



Chapter 5
MOISTURE

Water, an important part of the atmosphere, is found in three states: solid, liquid, and gaseous. As a solid, it takes the form of snow, hail, sleet, frost, ice-crystal clouds, and ice-crystal fog. As a liquid, it is found as rain, drizzle, and dew, and as the minute water droplets composing clouds and fog. In the gaseous state, water forms an invisible vapor.

Water vapor is the most important single element in the production of clouds and other visible weather phenomena. The availability of water vapor for the production of precipitation largely determines the ability of a region to support life. At the same time, however, it creates problems and sometimes hazards for the pilot when it changes into the liquid or solid state.

Most of the atmosphere's moisture is concentrated in the lower troposphere, and only rarely is it found in significant amounts above the tropopause.

The oceans are the primary source of moisture for the atmosphere, but it is also furnished by lakes, rivers, swamps, moist soil, snow, ice fields, and vegetation. Moisture is introduced into the atmosphere as water vapor, and may then be carried great distances by the wind before it is eventually removed as liquid or solid precipitation.

CHANGES OF STATE

In the change of water from a liquid to a gas, molecules escape from the surface of the liquid and enter the air as water vapor. The rate of their escape increases as the temperature at the liquid's surface increases. This is a simplified explanation of "evaporation," the process through which water vapor enters the atmosphere from liquid water.

Any change of state involves a heat transaction. In breaking away from the attraction of the other molecules, the escaping water molecules must do work and use energy, thus cooling the remaining liquid. The heat required for the evaporation process is not lost, but remains hidden or latent in the water vapor. When the vapor changes back to liquid water, this heat reappears. The more rapid the rate of evaporation, the greater is the cooling of the surface from which the heat is drawn.

During a period of high temperatures, light

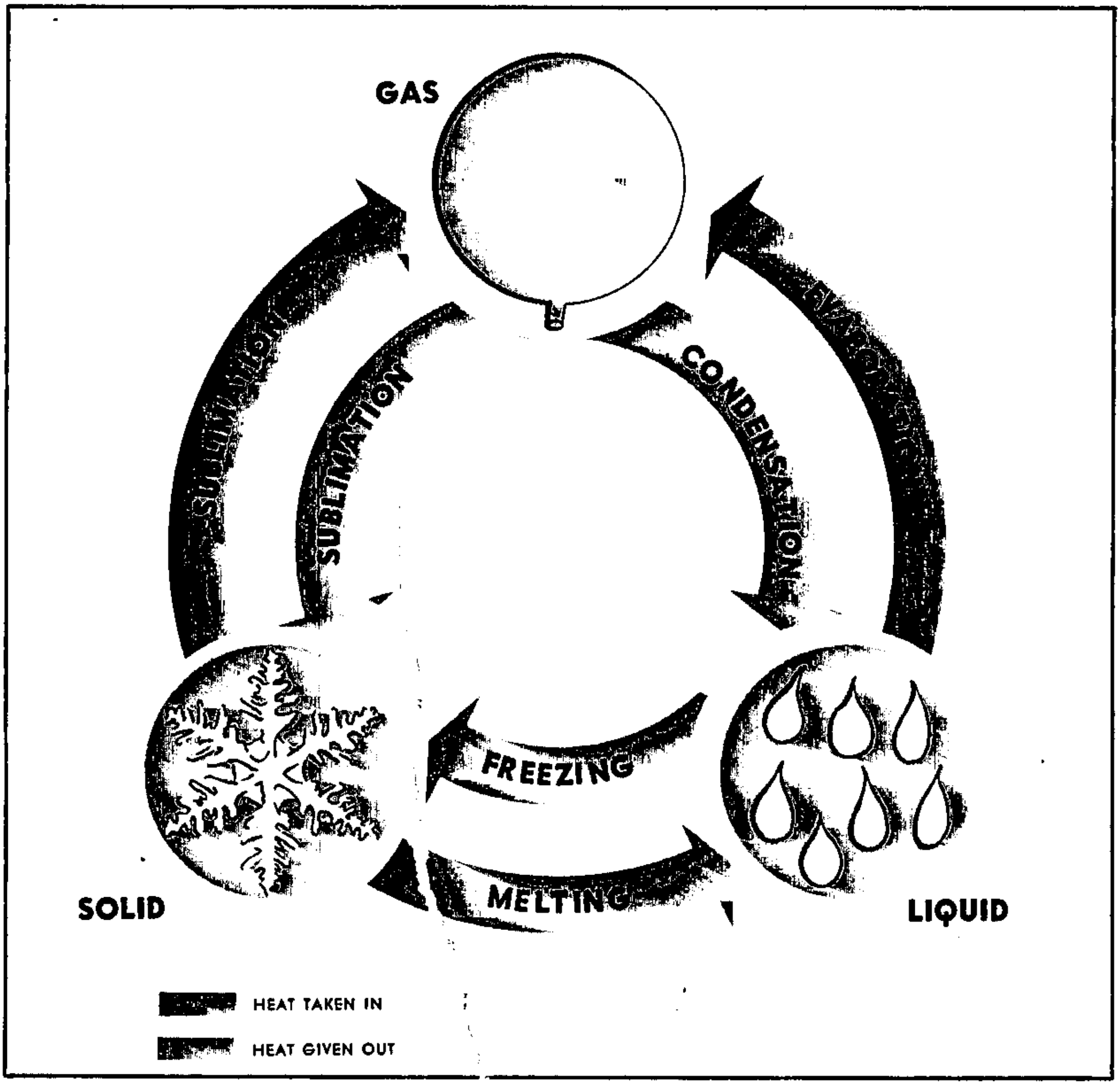


FIGURE 23. Changes of state.

winds, and high humidity, weather conditions tend to become oppressive. At such times, the body's perspiration evaporates very slowly and therefore produces little cooling. When we use a fan for cooling purposes, it moves away vapor-laden air near the skin, replacing it with drier air. As moisture in the skin evaporates into the drier air, much of the heat necessary to evaporate this moisture is removed from the skin, thus cooling the body more effectively.

Heat is also required to melt ice or snow into liquid water. Upon freezing, the same heat is released. Thus evaporation and melting both cool the air, or at least retard temperature increases that may be produced by other processes occurring simultaneously. Conversely, condensation (change of water vapor to liquid) and freezing raise the temperature of the air, or at least retard its rate of temperature decrease.

It is possible for ice to change directly to water vapor without passing through the liquid state. Many of us have at times observed the disappearance of snow on the ground with no melting. This process, called "sublimation," is somewhat like evaporation, but more heat energy is required for the escape of molecules from solid surfaces than from liquid surfaces. The heat required to sublimate a given amount of ice is the sum of the heat required to melt it and that required to evaporate the liquid water (even though no melting or evaporation takes place). Solid forms of precipitation, in addition to snow and ice surfaces, supply water vapor through the sublimation process. The amount of water vapor added to the atmosphere by the sublimation process is small compared to that added through evaporation.

Ice can form directly from water vapor. This process, which is the reverse of that described in the preceding paragraph, is also called sublimation, and is exemplified by the formation of frost on a cold, clear night.

The changes of state of water are illustrated in figure 23.

MOISTURE CONTENT

There is a limit to the amount of water vapor that air at a given temperature can hold. When this limit is reached, the air is said to be "saturated." The higher the air temperature, the more water vapor the air can hold before saturation is reached and condensation occurs (see fig. 24). For approximately every 20° F. (11° C.) increase in temperature, the capacity of a volume of air to hold water vapor is about doubled. Unsaturated air containing a given amount of water vapor will become saturated if its temperature decreases sufficiently; further cooling forces some of the water vapor to condense as fog, cloud, or precipitation.

RELATIVE HUMIDITY

Relative humidity is the ratio of the amount of water vapor actually in the air to the maximum amount the air can hold at that temperature. When the air contains all of the water vapor possible for it to hold at its temperature, the relative humidity is 100 percent. A relative humidity of 50 percent indicates that the air contains half of the water vapor which it is capable of holding at its temperature.

DEW POINT

The dew point is that temperature, at a given pressure, to which air must be cooled to become saturated. When this temperature is below freezing, it is sometimes called the "frost point." The difference between the actual air temperature and the dew point temperature is an indication of how close the air is to saturation. This temperature difference is commonly called the "spread." Relative humidity increases as the temperature spread decreases and is 100 percent when the spread is 0°.

The dew point is included in Aviation Weather Reports because it is a critical temperature, indicating the behavior of water in the atmosphere. When the surface air temperature is higher than the dew point, and the difference between the temperatures is increasing, any existing fog and low clouds are likely to dissipate because the air is becoming capable of holding

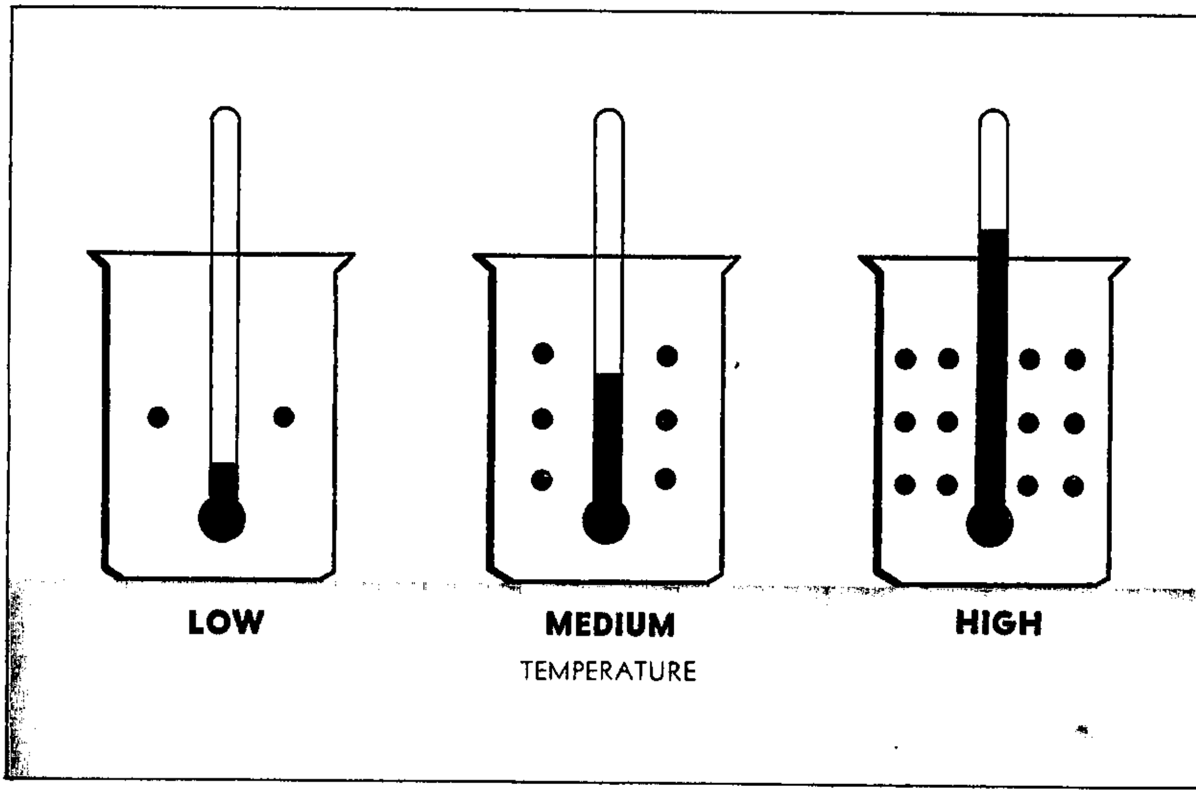


FIGURE 24. Blue dots illustrate the increased water vapor capacity of warmer air.

more water vapor. This is especially true in the morning hours when air temperature near the ground is increasing. On the other hand, pilots should be alert for the possibility of fog or low cloud formation at any time when the surface air temperature is within 4° F. of the dew point, and the spread between the two is decreasing.

CONDENSATION AND SUBLIMATION PRODUCTS

Condensation occurs if moisture is added to the air after saturation has been reached, or if cooling of the air reduces the temperature below the saturation point. The most frequent cause of condensation, cooling of the air, often results when (1) air moves over a colder surface, (2) air is lifted (cooled by expansion), or when (3) air near the ground is cooled at night as a result of radiational cooling.

CLOUDS AND FOG

The most common forms of condensation and sublimation products are clouds and fog. Except at temperatures well below freezing, clouds and fog are composed of very small droplets of water which collect on microscopic water-absorbent particles of solid matter in the air (such as salt from evaporating sea spray, dust, and products of combustion). The abundance of these particles on which the droplets form, called "condensation nuclei," permits condensation to occur generally as soon as the air becomes saturated.

Clouds and fog which form at temperatures well below freezing (—15° C. or lower) are usually composed of small particles of ice known as ice crystals, which form directly from water vapor, through the process of sublimation. However, liquid water droplets are frequently observed in the atmosphere at temperatures much lower than the freezing point, and sometimes even below —60° C., but rarely below —40° C. This situation, called "supercooling," is prevalent in clouds to a temperature of about —15° C. Aircraft penetrating supercooled clouds are likely to accumulate ice because the impact of the aircraft may induce freezing of the droplets.

PRECIPITATION

Precipitation is liquid or solid moisture that falls from the atmosphere in the form of rain, drizzle, sleet, snow, and combinations of them. The form of precipitation is largely dependent upon temperature conditions and the degree of turbulence present. Although there can be no precipitation without clouds, most clouds do not precipitate. Initial cloud particles are usually very small and remain suspended in the atmosphere. Precipitation occurs when the cloud particles grow sufficiently in size and weight to fall because of the gravitational pull of the earth. This growth can occur through a number of processes, but the production of snow is an example: Snowflakes grow as water in the supercooled droplets evaporates and then sublimates on ice crystals. In clouds with above freezing temperatures, collision of droplets of varying size is the most common process that produces precipitation (see fig. 25). Vertical air currents cause the droplets to collide and assist in the growth of clouds by carrying water vapor to higher altitudes. Usually precipitation of other than light intensity requires the cloud to be over 4,000 feet thick.

When the air is highly unstable, vertical currents in clouds are very strong, carrying supercooled water droplets or ice particles to high altitudes. Since these droplets become very large before and during their fall, resulting rain or snow is heavy.

Precipitation can change its state as the temperature of its environment changes. For example, falling snow may melt in warmer layers of air at low altitudes to form rain, or rain may fall into cooler layers and freeze into sleet before reaching the ground.

Sometimes strong vertical currents carry the

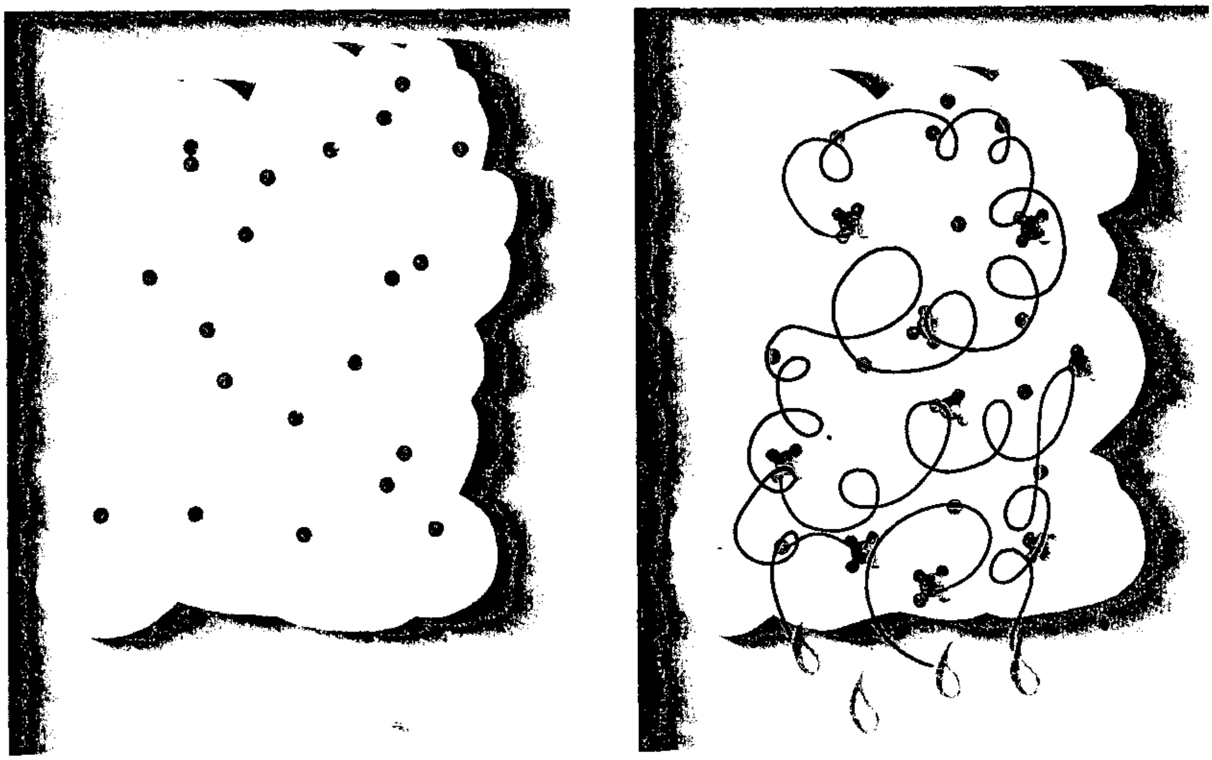


FIGURE 25. Growth of raindrops by collision of cloud droplets.

precipitation products up and down through repeated cycles of melting, sublimating, and/or freezing, leading to the formation of hail.

Precipitation does not necessarily reach the earth. On many occasions, it evaporates completely in dry air beneath the cloud base.

DEW AND FROST

During clear, still nights, vegetation often cools by radiation to a temperature at or below the dew point of the adjacent air. Moisture then collects on the leaves just as it does on a pitcher of ice water in a warm room. Heavy dew is often observed on grass and plants when there is none on the pavements or on large solid objects. These absorb so much heat during the day, or give up heat so slowly, that they do not cool below the dew point of the surrounding air during the night.

Dew does not fall; the moisture comes from the air in direct contact with the cool surface. When the temperature of the collecting surface is at or below the dew point of the adjacent air, and the dew point of the adjacent air is below the freezing point, frost, a sublimation product, will form instead of dew. Sometimes dew forms and later freezes, but frozen dew is easily distinguishable from frost since it is transparent and frost is opaque.

Chapter 6
STABILITY

To a pilot, the stability of his aircraft is a vital concern. A stable aircraft, if disturbed by the movement of the controls or by an external force, will tend to return to a balanced steady flight condition. An unstable aircraft, however, will continue to move away from the normal flight attitude.

So it is with the atmosphere. The normal flow of air tends to be horizontal. If this flow is disturbed, a stable atmosphere will resist any upward or downward displacement and will tend to return quickly to normal horizontal flow. An unstable atmosphere, on the other hand, will allow these upward and downward disturbances to grow, resulting in rough (turbulent) air. The clearest example of such unstable development in the atmosphere is the towering thunderstorm which grows as a result of a large and intensive vertical movement of air. It climaxes in lightning, thunder, and heavy precipitation sometimes including hail.

Atmospheric resistance to vertical motion, called "stability," depends upon the vertical distribution of the air's weight at a particular time. The weight varies with air temperature —hot air is lighter than cold air. Therefore, if air is warmer than its surroundings, it is forced to rise. For example, if a balloon is filled with air of the same temperature as the surrounding air, it will not rise—indicating a stable condition. On the other hand, a balloon filled with air which is warmer than the surrounding air will rise, since the atmosphere, which cannot resist this vertical motion, is unstable (see fig. 26). The atmosphere can only be at equilibrium when light air is above heavy air—just as oil mixed with water will rise to the top to obtain equilibrium.

In the same manner that the balloon with warm air rises, the air which is heated near the earth's surface on a hot summer day will rise too. The speed and vertical extent of its travel depend on the temperature distribution of the atmosphere. Vertical air currents resulting from the rise of air can vary from the severe updrafts and compensating downdrafts associated with thunderstorms, to the closely spaced upward and downward "bumps" that are felt on warm days when flying at low levels.

LAPSE RATES

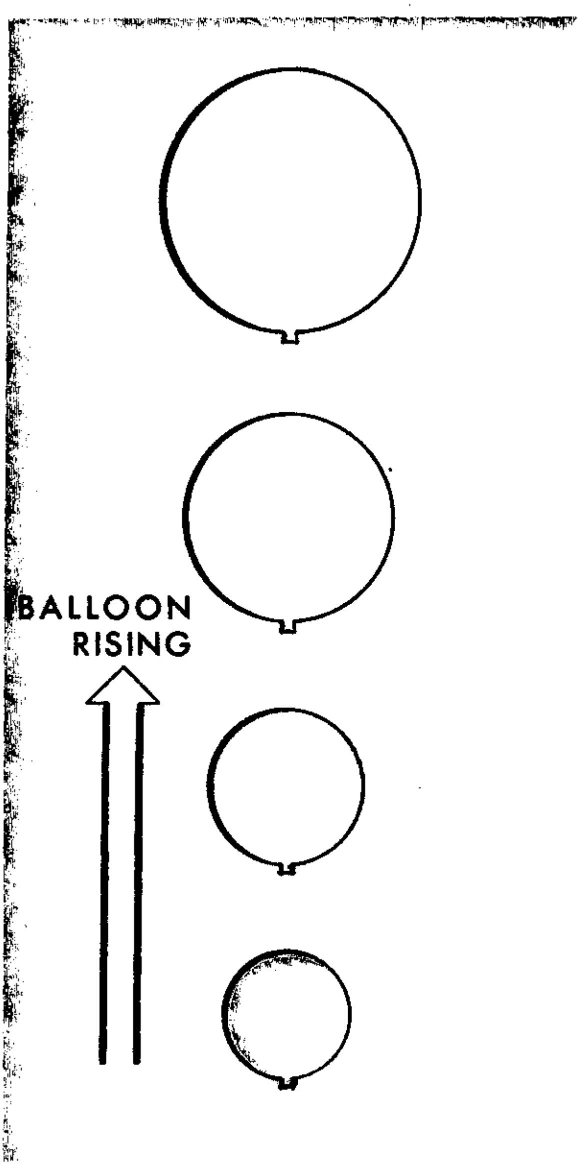


FIGURE 26. Air warmer than its surroundings rises, expands, and cools.

Since the temperature of air is an index of its density, a comparison of temperatures from one level to another can indicate the degree of the atmosphere's stability (that is, how much it will tend to resist vertical motion). Chapter 2 indicated that temperature usually decreases with altitude, and that the rate at which it decreases is called the "lapse rate." The lapse rate, commonly expressed in degrees per thousand feet, gives a direct measurement of the atmosphere's resistance to vertical motion. The degree of stability of the atmosphere may vary from layer to layer as indicated by changes of lapse rate with height.

DRY ADIABATIC LAPSE RATE

When *unsaturated* air rises, its temperature decreases at the rate of 3° C. (5½° F.) per 1,000 feet, whether the air is forced upward as a result of being heated from below, or through forced ascension such as up a mountain slope. This cooling rate of *unsaturated* air is known as the "dry adiabatic lapse rate."

Visualize the rising air as a "bundle" or "parcel" which is separate from the general atmosphere. The balloon in figure 26 is shown getting larger and larger with height because a rising parcel of air expands, causing it to cool. Heat, a form of energy, is consumed as air expands, thus removing heat from the air parcel and promoting a cooling of it. This is called an "adiabatic process," the word "adiabatic" meaning that the temperature change takes place without adding or taking away heat from outside of the air parcel. Warming by contraction (compression), the reverse of cooling by expansion, is also an adiabatic process.

MOIST ADIABATIC LAPSE RATE

When *saturated* air rises or is forced to ascend, condensation occurs, and the heat released as the result of condensation is absorbed by the air. This causes the air to cool at a slower rate than that of unsaturated air. The "moist adiabatic lapse rate" varies from approximately 1.1° C. (2° F.) to 2.8° C. (5° F.) per 1,000 feet, depending mostly on the temperature and to a small extent on atmospheric pressure. Since air can hold more water vapor at high temperatures than at low temperatures, a small decrease in the temperature of ascending *saturated* air at a high temperature causes a relatively large amount of moisture to condense. The amount of heat released by the condensation process is thus greater at high temperatures than at low temperatures, explaining why the moist adiabatic lapse rate is not a fixed value.

The warm, dry "chinook" wind, mentioned in chapter 4, is a dramatic example of the difference between the *moist* and *dry* adiabatic lapse rates. In winter, moist air from the Pacific Ocean is occasionally forced over the Rockies by a strong wind flow. Assume that at 5,000 feet on the western slope, the air is saturated and has a temperature of 44° F. Blowing over the mountains, the air is lifted to 12,000 feet (see fig. 27). Because it is saturated, the air cools at the moist adiabatic rate, with condensation occurring throughout the 7,000 feet of rise. At 12,000 feet its temperature is 21° F., having cooled at an average rate of 3.3° F. per 1,000 feet. Descending the eastern slope of the mountains the air warms at the dry adiabatic lapse rate. As soon as the air starts to descend, its temperature increases due to compression (contraction), and it is no longer saturated. Thus the descending air, warming at 5½° F. per 1,000 feet, arrives at 5,000 feet on the east side with a temperature of 60° F. In crossing the mountains, its temperature has increased 16° F. and its relative humidity has decreased considerably.

DEW POINT LAPSE RATE AND CLOUD HEIGHTS

As indicated in the preceding chapter on moisture, the difference between the air's temperature and dew point gives an indication of its relative humidity. When they are the same, the relative humidity is 100 percent, the air is saturated, and condensation may be expected. The "dew point lapse rate" is 1° F. (.56° C.) per 1,000 feet during a lifting process. The temperature and dew point in rising unsaturated air, therefore, approach each other at a rate of 4½° F. (5½° F. minus 1° F.) per 1,000 feet.

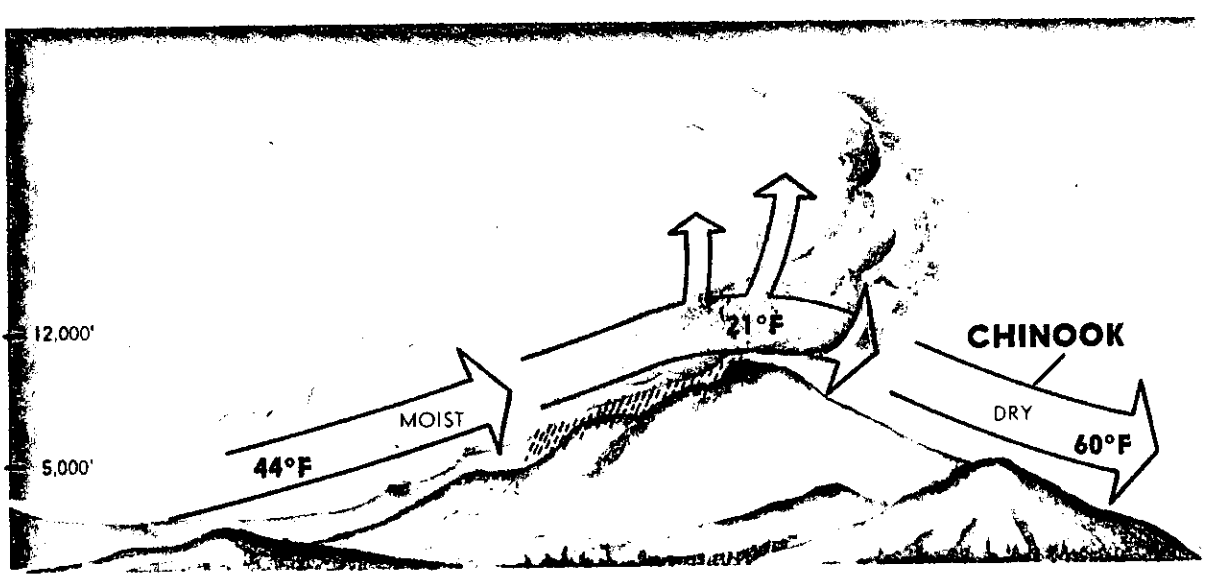


FIGURE 27. Forced air flow over mountains results in the "chinook".

Knowing the surface air temperature and dew point, one can readily estimate the level at which condensation will occur when air rises. By dividing the difference between the surface air temperature and the dew point by $4\frac{1}{2}°$ F., the height of cloud bases can be estimated in thousands of feet. For example, if the surface air temperature is 80° F. and the surface dew point is 62° F., the approximate height of the base of the clouds formed by this lifting process is 4,000 feet (18° F. ÷ $4\frac{1}{2}°$ F. = 4). This is graphically illustrated in figure 28.

The foregoing method of estimating the height of cloud bases is reliable only on warm days when the earth's surface is heated a great deal by the sun. This process is discussed further in the next chapter.

STANDARD LAPSE RATE

The "standard lapse rate" is the average rate at which the atmosphere cools with increasing altitude. This cooling rate, approximately 2° C. ($3\frac{1}{2}°$ F.) per 1,000 feet, is an average determined by evaluating thousands of atmospheric soundings from various parts of the world.

While the standard lapse rate is used in the United States and most of the world as a basis for calibrating aircraft altimeters, it has no connection with determining the stability of air on a day-to-day basis. However, the following may be concluded from the standard lapse rate: (1) unsaturated air, on the average, is stable; (2) saturated air at high temperatures is normally unstable; and (3) saturated air at low temperatures, on the average, is stable. Stated another way, the general conclusion is that air at moderate and high temperatures is normally either stable or unstable depending upon the amount of moisture it contains. These facts may be better understood after an examination of the full significance of *dry* and *moist* adiabatic lapse rates in determining the atmosphere's stability from day to day.

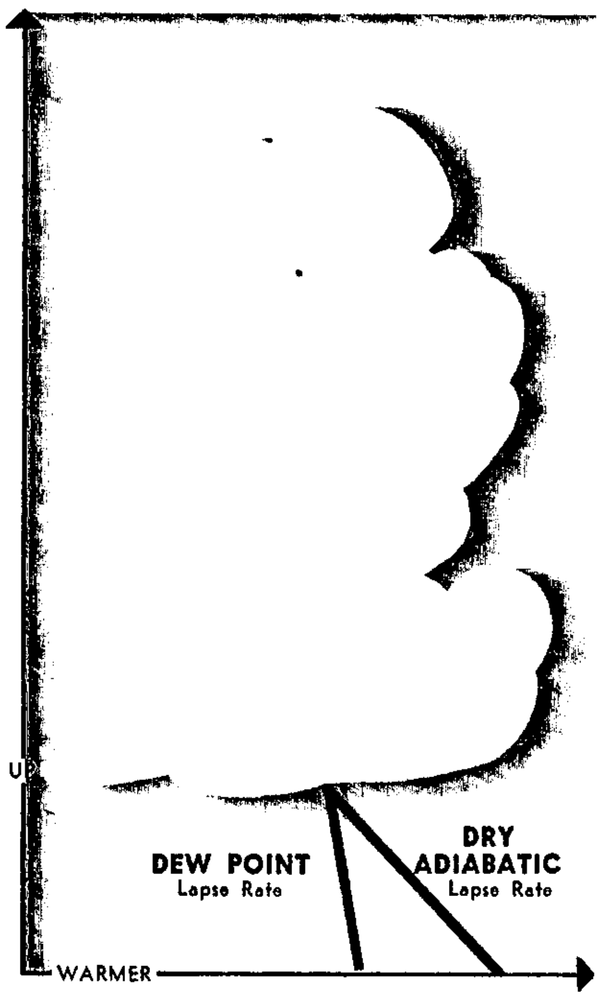


FIGURE 28. Cloud base determination.

STABILITY DETERMINATIONS

By comparing the actual lapse rate of layers of air with the dry and moist adiabatic lapse rates, the degree of stability of each layer may be determined. To simplify this determination, data from the atmospheric sounding are plotted on an "adiabatic chart" (see fig. 29). Since an adiabatic chart is a tool of the weatherman, a simplified version of the chart may be used to demonstrate how the varying degrees of stability are determined (see fig. 30).

ABSOLUTE STABILITY

When the actual lapse rate in a layer of air is *less than* the *moist* adiabatic lapse rate, that air is absolutely *stable*, regardless of the amount of moisture it contains. In figure 30, a plot of

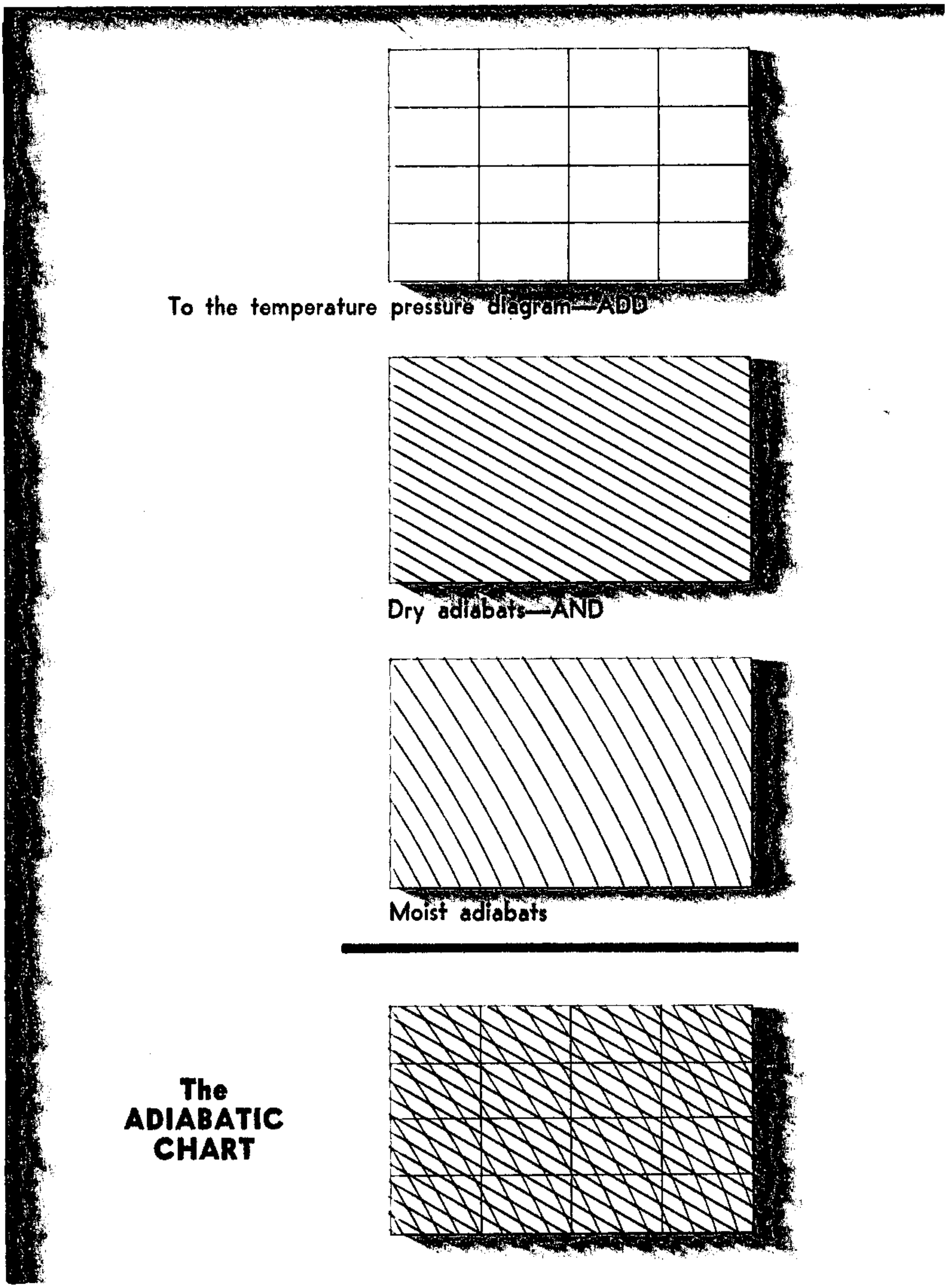


FIGURE 29. The adiabatic chart.

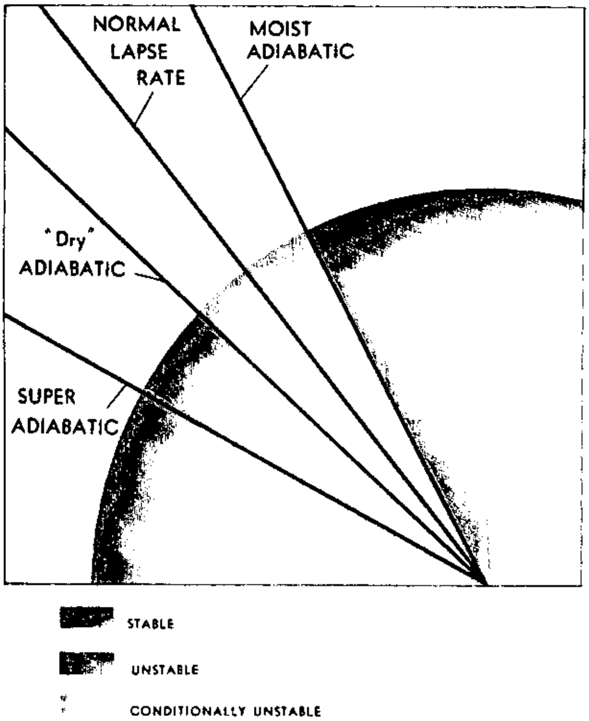


FIGURE 30. The degree of air stability in relation to the rate at which temperature changes with height.

the actual lapse rate falls to the right of the moist adiabat. A parcel of absolutely stable air which is lifted becomes cooler than the surrounding air and sinks back to its original position as soon as the lifting force is removed. Similarly, if forced to descend, it becomes warmer than the surrounding air and, like a cork in water, rises to its original position upon removal of the outside force.

ABSOLUTE INSTABILITY

When the actual lapse rate in a layer of air is *greater than* the *dry* adiabatic lapse rate, that air is absolutely *unstable,* regardless of the amount of moisture it contains. The plot of the actual lapse rate lies to the left of the dry adiabat. A parcel of air lifted even slightly will at once be warmer than its surroundings and, like a hot air balloon, will be forced to rise rapidly.

CONDITIONAL STABILITY

When the actual lapse rate lies between the dry and moist adiabats, the air is conditionally stable. If the air is saturated, it will be unstable; if unsaturated, it will be stable. In other words, whether the air is stable or unstable depends upon the amount of moisture it contains. The standard lapse rate lies between the dry and moist adiabats, indicating that, on the average, air is conditionally stable.

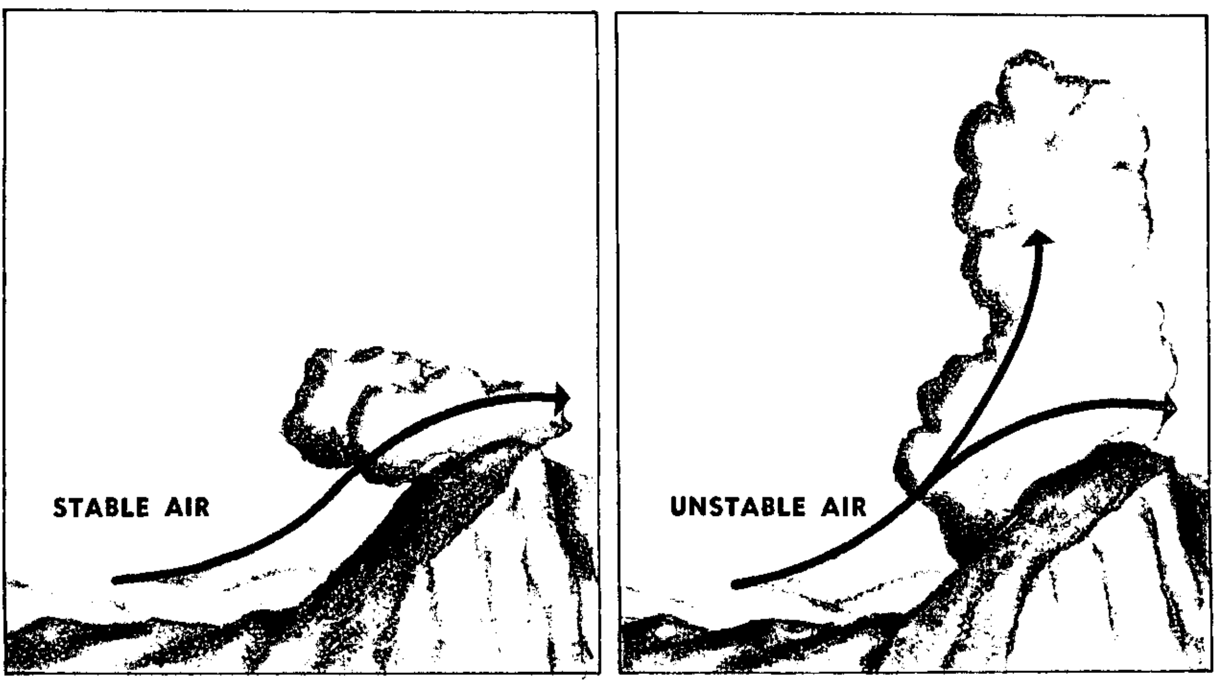


FIGURE 31. The effect of stability on cloud structure.

SOME EFFECTS OF STABILITY AND INSTABILITY

The degree of stability of the atmosphere helps to determine the type of clouds, if any, which form. For example, if very stable air is forced to ascend a mountain slope, clouds will be layerlike with little vertical development and little or no turbulence (see fig. 31). Unstable air, if forced to ascend the slope, would cause considerable vertical development and turbulence in the clouds.

If air is subsiding (sinking), the heat of compression frequently causes an inversion of temperature, increasing the stability of the subsiding air. Sometimes when this occurs, often in wintertime high pressure systems, a surface inversion formed by radiational cooling is already present. The subsidence-produced inversion, in this case, will intensify the surface inversion, placing a strong "lid" above smoke and haze. Poor visibility in the low levels of the atmosphere results, especially near industrial areas. Such conditions frequently persist for days, notably in the Great Basin region of the western United States.

Chapter 7
TURBULENCE

Turbulence affecting aircraft ranges all the way from a few annoying bumps to severe jolts which are capable of producing structural damage. Since turbulence is associated with many different weather situations, a knowledge of its causes and the behavior of irregular air movements is helpful in avoiding or minimizing the effects of this disturbed air.

The atmosphere is considered turbulent when irregular whirls or eddies of air affect aircraft so that a series of abrupt jolts or bumps is felt. A large range of eddy sizes exists, but those causing the bumpiness are roughly of the same size as the aircraft. The eddies usually occur in an irregular sequence. The reaction to the turbulence varies not only with the intensity of the irregular motions of the atmosphere, but also with aircraft characteristics such as flight speed, wing loading, and aircraft attitude.

The main causes of turbulence are (1) vertically moving air in convective currents, (2) air moving around or over mountains and other obstructions, and (3) wind shear. Two or even all three of these factors are often acting in a turbulent area at one time.

CONVECTIVE CURRENTS

Convective currents, one of the main causes of bumpiness or turbulence experienced by pilots flying at low altitudes in warm weather, are localized vertical air movements, both *ascending* and *descending*. For every rising current, there is a compensating downward current. At

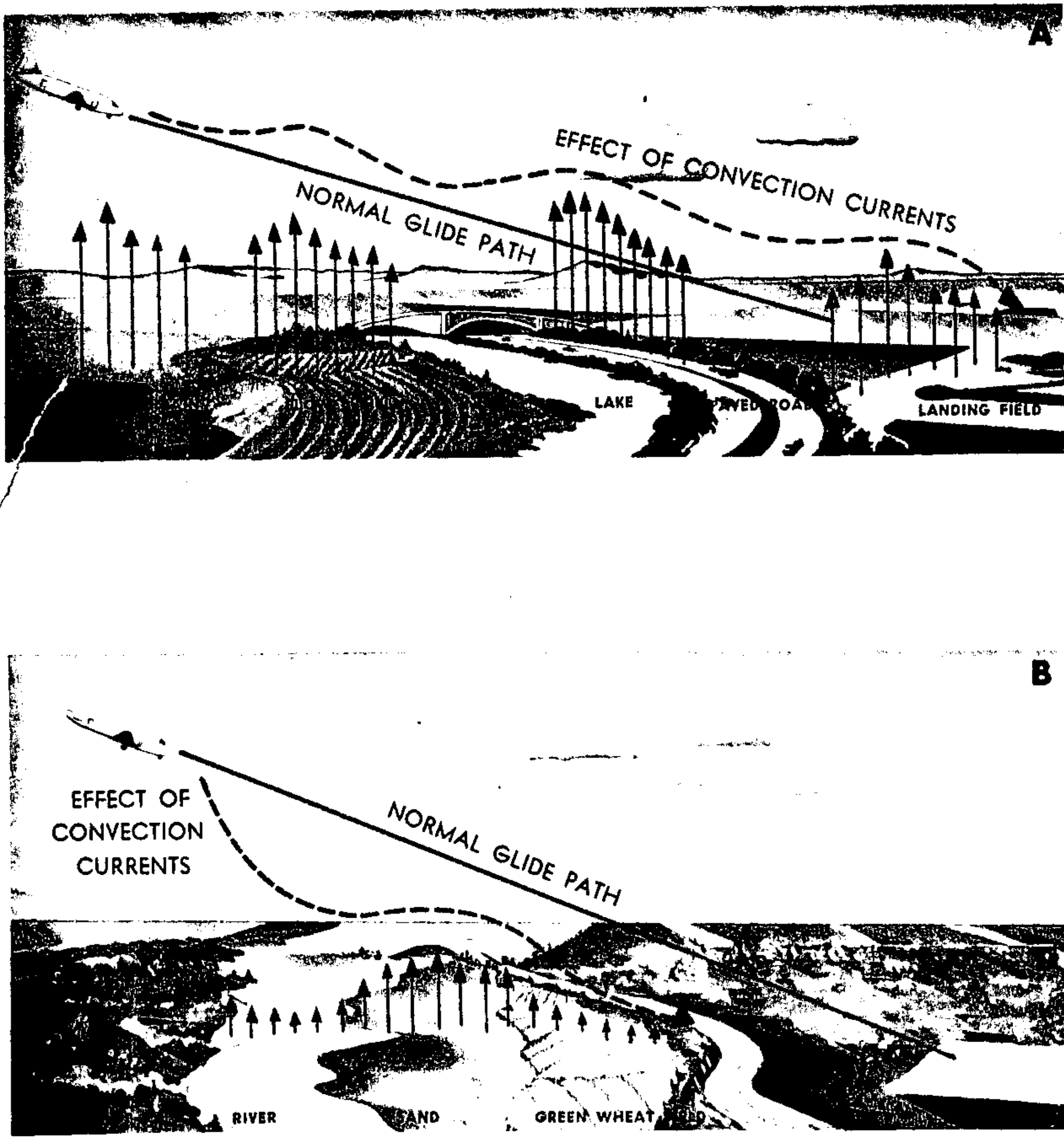


FIGURE 32. The effect of convective currents on the final approach—overshooting (A) and undershooting (B), depending on the strength and distribution of convection.

times, this downward current may occur over a broad area and be of a much slower speed than the rising current. As clouds form on a typical summer afternoon, there are rising currents of air beneath and within the clouds, while compensating downward currents are found in the clear air between the clouds.

Convective currents develop in air which is heated by contact with a warm surface. They therefore are most active on warm summer afternoons with a light wind, since a strong wind flow tends to break up the currents. If the wind is light, bubbles of heated air (sometimes up to several hundred yards in diameter) form near the ground. They rise as convective currents until they reach a level where their temperature is the same as that of the surrounding air. The strength of the currents increases as surface heating increases. Barren surfaces, such as sandy or rocky wasteland and plowed fields, heat faster than ground covered by grass or other vegetation. Thus, variations in the composition of the surface result in uneven heating of the air near the ground, causing convective currents to vary in strength within short distances. Figure 32 illustrates this effect on aircraft approaching an airport for landing. The rough air resulting from convective currents is often referred to as "thermal turbulence."

Land and sea breezes, discussed in chapter 4, are good examples of very active convection. Even when the general wind flow is sufficiently strong to prohibit development of a sea breeze, the differential heating of the land and sea causes enough convection for pilots to experience turbulence when crossing shorelines on hot summer days.

Pilots learn to associate convective currents with dense, dome-shaped clouds (cumulus) and large, towering clouds with anvillike tops (cumulonimbus). Sometimes, however, convective currents are present in the absence of clouds. These currents may be active although the air is too dry for cloud formation. When these clouds are not growing appreciably, the pilot ordinarily will find smooth air above them (illustrated in fig. 33). The most severe turbulence found in and around clouds is normally in association with thunderstorms. This will be discussed in detail in chapter 11.

Heating from below makes the air unstable. If the atmosphere is unstable even before the heating begins, convective currents will be sustained, or even accelerated, by the heated atmosphere.

Cold air moving over a warm surface is also heated from below, causing the air to become

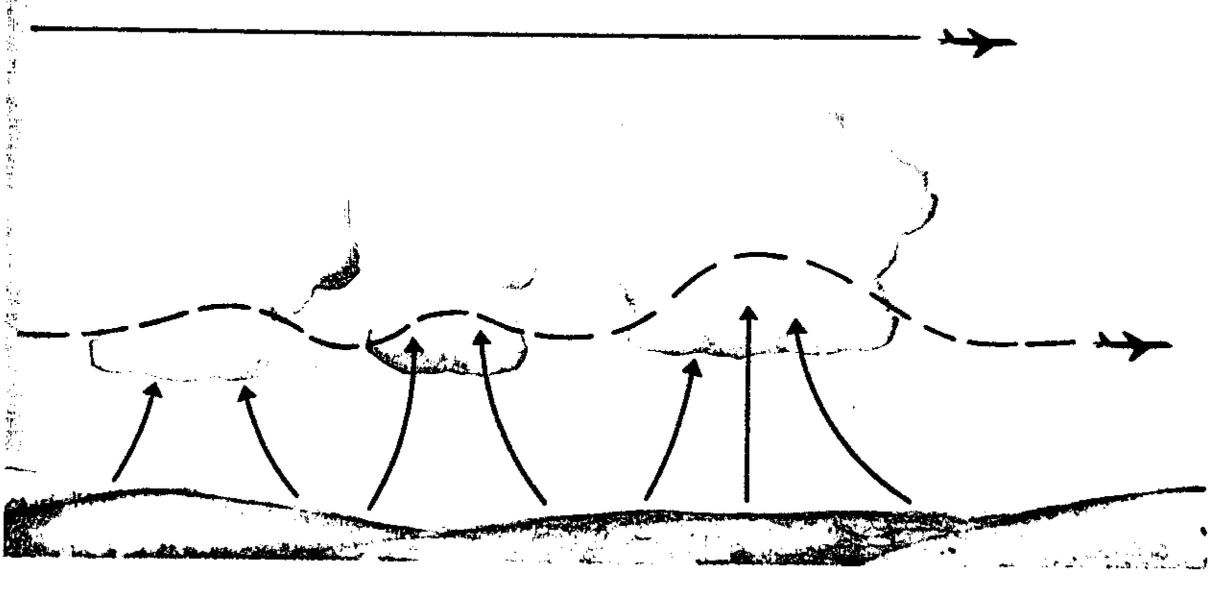


FIGURE 33. Avoiding turbulence by flying above clouds.

unstable and bumpy to altitudes of several thousand feet or more above the surface. Sometimes a similar situation occurs aloft when air is cooled by lifting, or when cold air aloft moves into the area. Convective currents cause turbulence in a layer usually several thousand feet thick. If sufficient moisture is available, round or roll-like clouds will mark the layer.

The frequency of bumpiness increases with the speed of flight through a series of convective currents. At high speeds, more up and down currents are crossed during a given time interval, the increased speed causing the turbulence to seem more severe due to the more rapid changes in the vertical motion of the aircraft. The lighter and slower the aircraft, the more susceptible it is to displacements from its flight path. Thus aircraft size, its speed, and weather conditions are interrelated in determining the turbulence a particular pilot will experience.

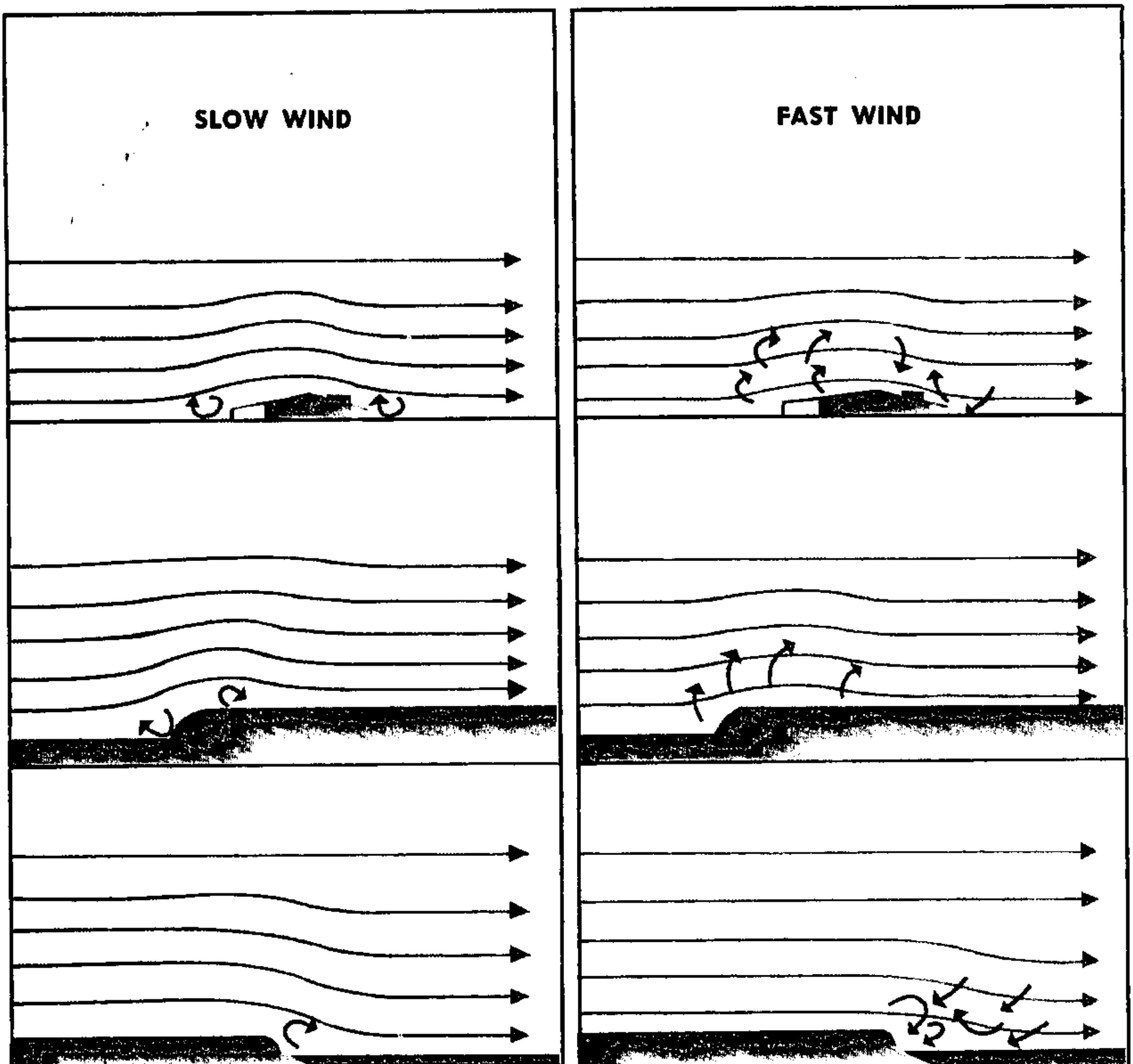


FIGURE 34. Eddy currents formed by winds blowing over uneven ground or obstructions.

OBSTRUCTIONS TO THE WIND FLOW

Turbulence, occurring when air near the surface of the earth flows over rough terrain or other obstructions, is a mechanical process. Where countless obstacles such as trees, buildings, and hills block its path, the normal wind flow is transformed into a vastly complicated snarl of eddies similar to rapids in a stream but more complex (see fig. 34). These eddies tend to be carried along with the general wind flow, their size and extent affecting the flying characteristics of aircraft. The degree of turbulence experienced by aircraft flying at low levels over rough terrain depends on the roughness of the terrain, the wind speed, and the degree of stability of the air mass. Quick-response indicators observing wind in an area of rough terrain, or where other obstructions exist, show a great variability of both wind speed and direction, with brief, sudden, and irregular periods of low speeds (lulls) and of high speeds (gusts). Variability in speed tends to increase as the average speed of the general wind flow increases, while wind direction tends to become less variable with the increase.

Variability of wind near the ground is an extremely important consideration during takeoff and landing, especially for light aircraft. Gusty winds have caused many aircraft accidents, and pilots landing at airports where large hangars or other buildings are located near the runways should be alert for turbulent eddies (see fig. 35). If the wind is light, eddies tend to remain as rotating pockets of air near the windward and leeward sides of the buildings. But, if the wind speed exceeds about 20 knots, the flow may be broken up into irregular eddies which are carried a sufficient distance downstream to create a hazard in the landing area.

Air moving slowly over a fairly smooth surface, such as rolling hills, usually causes minor turbulence, with the effects most noticeable within a few hundred feet of the ground. When the wind blows faster and the obstructions are larger, turbulence increases and extends to higher levels.

A much disturbed condition occurs when wind blows over large mountain ridges. The wind blowing up the windward slope, in a stable atmosphere, is usually relatively smooth. However, it spills rapidly down the leeward side, setting up strong downdrafts and causing turbulence in a situation which can be compared to water flowing down a rough stream

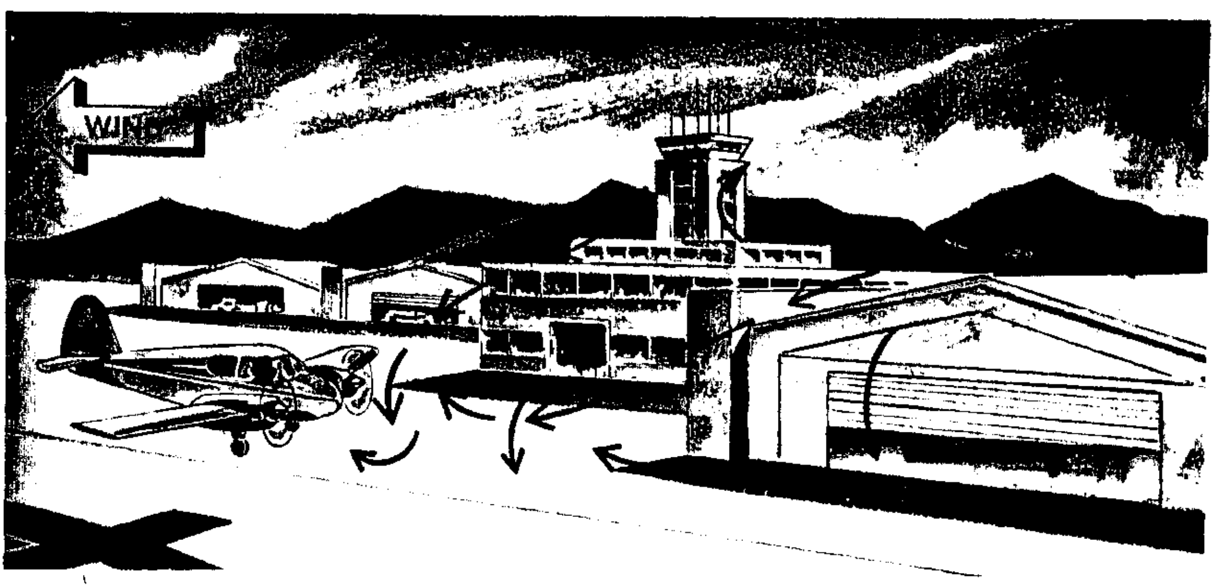


FIGURE 35. Turbulent air in the landing area.

bed (see fig. 36). These downdrafts may be dangerous and can place an aircraft in a position from which it might not be able to recover. Pilots should allow for this condition when approaching mountain ridges against the wind. If the wind is strong and the ridges pronounced, several thousand feet above the highest obstruction is recommended in crossing the area. It is important to climb to the crossing altitude well before reaching the mountains to avoid having to climb (or trying to climb) in a persistent downdraft.

Pilots should be extremely cautious when attempting to cross high mountain ranges under strong wind conditions because winds over ridges and through passes and narrow valleys usually are much stronger and more turbulent than the general wind flow. In addition, the wind usually blows in the direction of the passes and valleys, rather than in the direction of the general wind flow.

When winds in excess of about 50 knots blow approximately perpendicular to a high mountain range, the resulting turbulence may be extreme. Associated areas of steady updrafts and downdrafts can extend many times higher than the elevation of the mountain peaks, with large waves forming on the leeward side of the mountains and extending upward to beyond the troposphere. In the horizontal dimension, these air waves (see fig. 37), referred to as "standing waves" or "mountain waves," sometimes extend as far as 100 miles or more downstream from the mountain range. Reports of turbulence in these waves range from none to severe, but most pilots encounter moderate to severe turbulence.

Probably the most dangerous characteristic of the standing wave is the magnitude of the sustained updraft and downdraft. Standing waves such as the Sierra Wave are common in the Rocky Mountains and occur in other mountainous areas in varying magnitudes. There have been reports of this type of wave in the comparatively low Appalachian Mountains.

Crests of standing waves sometimes are marked by stationary, lens-shaped clouds, and the "rotor" area may be marked by a cloud formation whose motions indicate the violent air

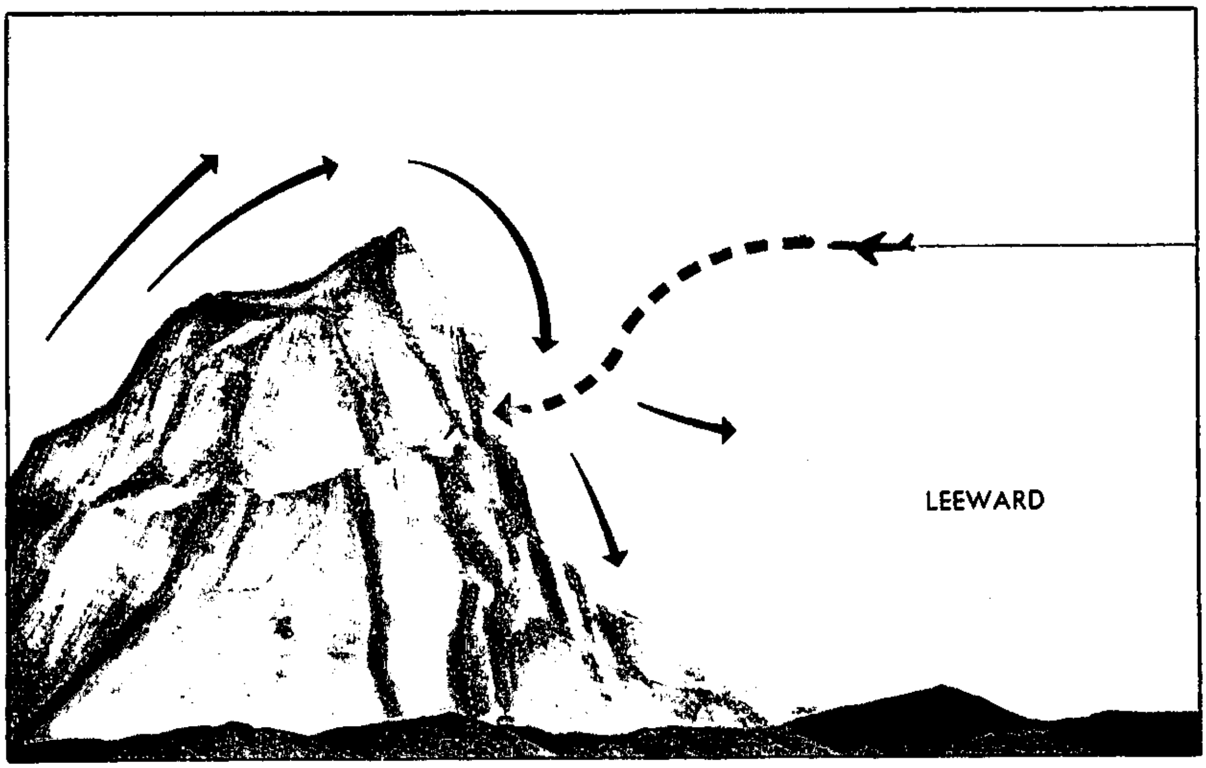


FIGURE 36. Wind flow near mountains.

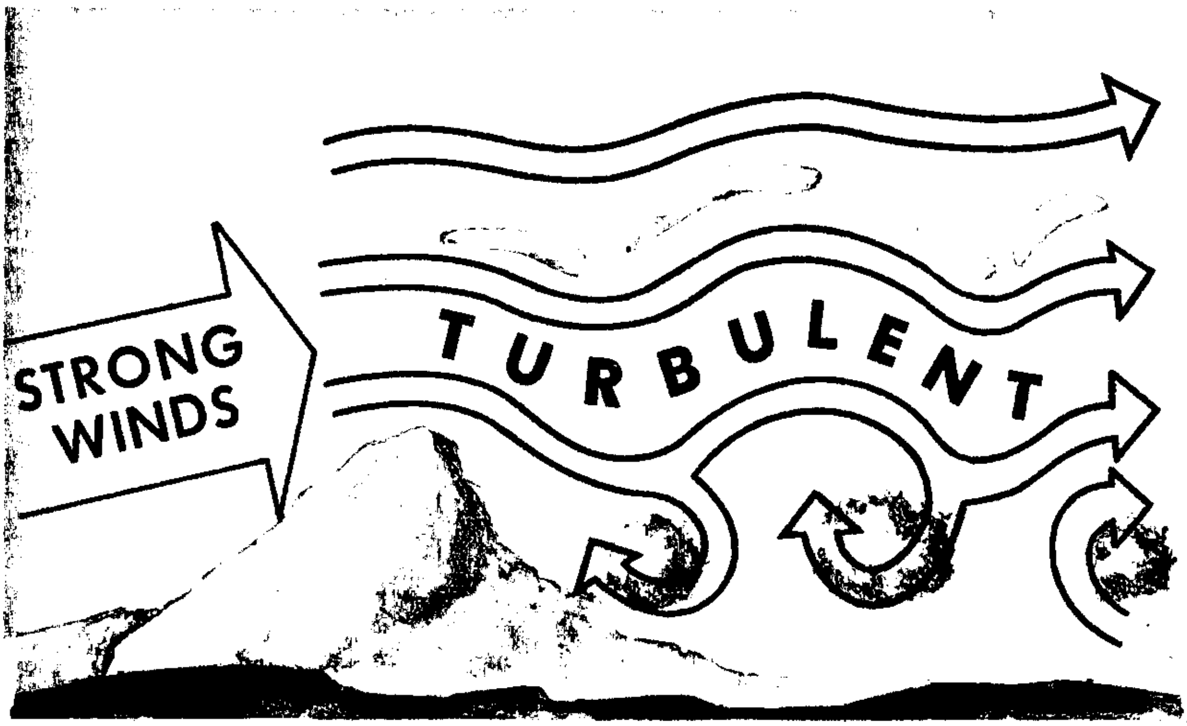


FIGURE 37. A mountain wave.

currents. At times, however, there is insufficient moisture to form these clouds and, therefore, there is no visible indication that this condition exists. Rotor action is usually most violent near leeward slopes which drop off sharply.

For practical purposes, possible standing waves should be anticipated to the lee of major mountain ranges when winds are blowing across the mountains in excess of 50 knots. Because of the very disturbed air flow in standing waves, there may be substantial local reductions or increases in air pressure, thereby making altimeter readings unreliable. Readings 1,000 feet higher than the actual altitude are not uncommon in high mountainous areas.

WIND SHEAR

Wind shear is a change in wind speed and/or wind direction in a short distance, resulting in a "tearing" or "shearing" effect. It can exist in a horizontal or vertical direction and, occasionally, in both. Wind shear, which can be present at any level, produces churning motions (eddies) resulting in turbulence. The degree of turbulence increases as the amount of wind shear increases.

A narrow zone of wind shear, with its accompanying turbulence, is often encountered when an aircraft climbs or descends through a temperature inversion; wind speed and/or direction sometimes changes very abruptly with altitude in this zone.

A potential hazard to aircraft immediately after takeoff or on the final approach for landing is an extreme form of wind shear associated with strong temperature inversions near the ground. In a typical case, intense nighttime radiational cooling forms a pocket of very cold air in the valley where the airport is located (see fig. 38). This air, only a few hundred feet thick, is underneath a moving layer of warmer air. Because of the difference in speed between the warm air and the trapped air, a narrow zone of wind shear forms along their boundaries. An aircraft climbing or descending through this zone may encounter a large loss of airspeed. If the wind direction in the warm air is the same as the direction of a climbing aircraft, the abrupt change in wind speed can cause a substantial loss of altitude or airspeed. This situation can be dangerous since the zone is only a few hundred feet above the ground. The intensity of turbulence varies mostly with the speed of the warm air, since the cold air is about calm. The condition described here occurs almost entirely in winter in the colder climates (northern States and Canada).

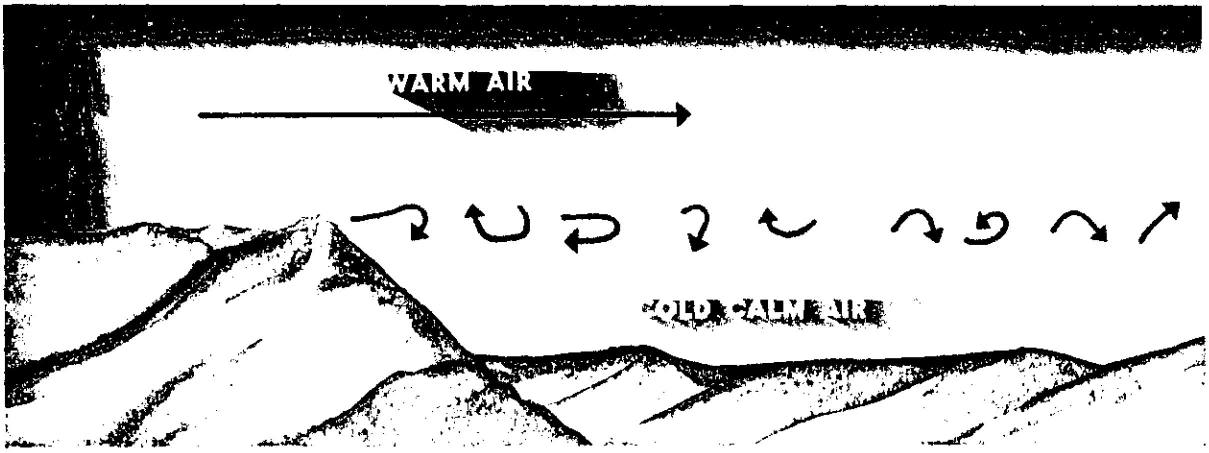


FIGURE 38. Turbulence in a zone of wind shear.

CLEAR AIR TURBULENCE

The shapes of any clouds which may be present can serve as warning signals for the presence of turbulence. The pilot may choose to avoid these turbulent clouds, or to penetrate them (assuming, if on an IFR clearance, that Air Traffic Service can permit a choice in the particular situation). The pilot is forewarned of turbulence when disturbed-looking clouds mark its presence, and he can slow his aircraft or take other recommended actions to cope with it.

Unfortunately, turbulence may be present with *no visual warning.* Many aircraft, in a cloudless sky, have been jolted and bounced as if they were speedboats racing on a choppy sea. "Clear air turbulence," which can occur at any level, is caused by convective currents, obstructions to the wind flow, wind shear, or any combination of these previously discussed causes of turbulence. High-level clear air turbulence is discussed in chapter 19.

WAKE TURBULENCE

Light planes especially are affected by the swirls of air in the wake of larger aircraft. Figure 39 illustrates how these might look, if visible, behind a plane on its takeoff run. The effect of these eddies, caused by airfoils disturbing the air, is much like the effect of those caused by buildings and other sizable obstructions, except that the eddies behind aircraft are often larger in size and more violent. This invisible turbulence can be extremely dangerous during takeoff and landing. Numerous aircraft have encountered wake turbulence of such severity that complete loss of control of the aircraft resulted. The aircraft were, in some cases, at altitudes too low to recover. Some of the most severe wake turbulence is produced by commercial jet aircraft in landing configuration.

Wake turbulence normally is encountered only within a minute or two after the passage of

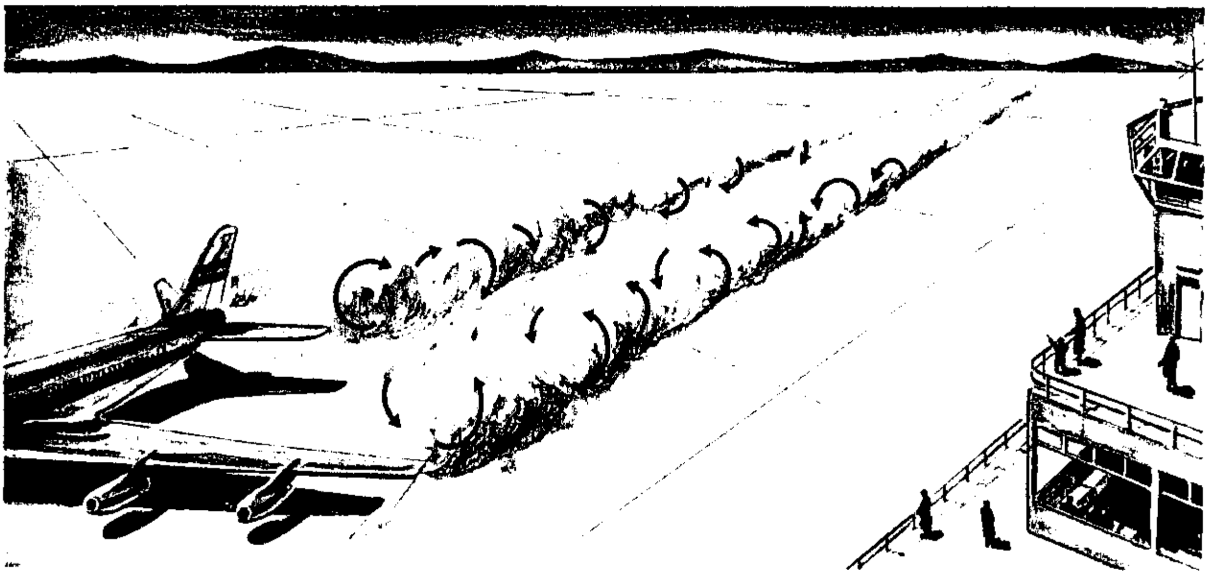


FIGURE 39. Clear air turbulence in the wake of an aircraft.

an aircraft. However, it may persist for five minutes or longer if the air is otherwise calm and stable, a condition which also increases its severity. Although the severity of wake turbulence diminishes as the general wind flow increases, the distance the turbulence may be felt increases since the eddies drift downwind from the path of the aircraft which is producing them.

Since light aircraft generally start their final approach nearer the runway than larger aircraft, they sometimes encounter wake turbulence at very low altitudes when landing behind aircraft with a longer and shallower approach path. It is safer for pilots of light aircraft to allow several minutes before landing or taking off behind these larger aircraft if the wind is light.

Turbulence, sometimes of "severe" intensity, may be encountered aloft when flying in the wake of another aircraft. Similarly, an aircraft may experience a sharp jolt in crossing its own wake when completing a 360° turn.

CATEGORIES OF TURBULENCE INTENSITY

Classification of turbulence intensities is a difficult problem for both the pilot reporting an encounter and the forecaster predicting it. This problem is due largely to the great number and variety of personal, operational, and weather factors involved. If two or more pilots flying separate but identical aircraft encounter the same degree of turbulence, their individual evaluations of its intensity are likely to vary considerably. Experience has shown that individual crew members of the same aircraft often do not agree on the degree of turbulence which they encountered. Each pilot judges the severity of the turbulence on the basis of his training, experience, and individual mental reaction.

Among the characteristics influencing aircraft reaction to turbulence are airspeed, weight, wing loading, attitude, and configuration. The same aircraft may react differently to turbulence after burning off some of its fuel than it did during the early portion of its flight.

The weatherman has no direct measurement of turbulence either. He has a good knowledge of terrain features, usually a considerable amount of experience, and certain meteorological "indicators," such as temperature lapse rates, wind shears, etc. However, the meteorological indicators most valuable to him are available only at infrequent intervals, and even they cannot be measured directly.

These indicators of turbulence are based on "raw" data from atmospheric soundings. The "raw" data must pass through several processes before lapse rates and wind shears are known to the forecaster.

The forecaster is more dependent on pilot reports in predicting turbulence than in predicting almost any other atmospheric condition. Information on turbulence experienced by pilots is valuable to other pilots as well as to the forecaster in judging the degree of turbulence to anticipate. Even though the reports provide no absolute measurement, it is subjectively judged that the atmosphere is more disturbed if a large aircraft, for example, reports "moderate turbulence" than if a light aircraft reports the same intensity. Through experience, one obtains a fairly good idea of the actual turbulence which exists from the various intensities reported from aircraft of different types.

For many years government and private scientists have worked to solve the problems of objectively determining the intensities of turbulence encounters, of relating information on turbulence to other atmospheric conditions, and of developing a common language between the forecaster and the pilot in expressing the degree of turbulence. Much in-flight research has been included in this effort. Derived gust velocities determined by accelerometers, while still not an absolute measure of turbulence, have proven to be the best indicator for turbulence intensity so far known. The National Aeronautics and Space Administration developed the Turbulence Criteria Table shown in figure 40. The derived gust velocity criteria found in the table appear to provide the most suitable bridge, now available, between aircraft design characteristics and atmospheric turbulence as related to flight operations. This table has been adopted as standard by weather agencies.

Adjective Class	Transport Aircraft Operational Criteria	Derived Gust Velocity Criteria
Light	A turbulent condition during which occupants may be required to use seat belts, but objects in the aircraft remain at rest.	5 to 20 feet per second.
Moderate	A turbulent condition in which occupants require seat belts and occasionally are thrown against the belt. Unsecured objects in the aircraft move about.	20 to 35 feet per second.
Severe	A turbulent condition in which the aircraft momentarily may be out of control. Occupants are thrown violently against the belt and back into the seat. Objects not secured in the aircraft are tossed about.	35 to 50 feet per second.
Extreme	A rarely encountered turbulent condition in which the aircraft is violently tossed about, and is practically impossible to control. May cause structural damage.	More than 50 feet per second.

FIGURE 40. Turbulence criteria table.

While the typical pilot is unable to report turbulence intensity by derived gust velocity criteria, the descriptive terms in the table have meaning to everyone. Based on transport type aircraft, these descriptions give a starting point from which users of turbulence forecasts can evaluate intensities. These evaluations must be made in the light of their own operational and personal limitations.

Basing turbulence intensity on the effect it has on transport aircraft, the following are weather situations in which the various intensities of turbulence are most likely to be encountered. Part of the information has already been presented, but since this combined rough guide to turbulence classes is used by aviation forecasters in the Weather Bureau, it may be helpful for the pilot. Mechanically produced turbulence, other than that caused by mountains, is excluded.

LIGHT TURBULENCE

1. In hilly and mountainous areas even with light winds.
2. In and near small cumulus clouds.
3. In clear-air convective currents over heated surfaces.
4. With weak wind shears in the vicinity of:
   a. Troughs aloft.
   b. Lows aloft.
   c. Jet streams.*
   d. The tropopause.*
5. In the lower 5,000 feet of the atmosphere:
   a. When winds are near 15 knots.
   b. Where the air is colder than the underlying surfaces.

MODERATE TURBULENCE

1. In mountainous areas with a wind component of 25 to 50 knots perpendicular to and near the level of the ridge:
   a. At all levels from the surface to 5,000 feet above the tropopause with preference for altitudes:
      (1) Within 5,000 feet of the ridge level.
      (2) At the base of relatively stable layers below the base of the tropopause.
      (3) Within the tropopause layer.
   b. Extending outward on the lee of the ridge for 150 to 300 miles.
2. In and near thunderstorms in the dissipating stage.
3. In and near other towering cumuliform clouds.
4. In the lower 5,000 feet of the troposphere:
   a. When surface winds exceed 25 knots.
   b. Where heating of the underlying surface is unusually strong.
   c. Where there is an invasion of very cold air.
5. In fronts aloft.

*For more information on turbulence associated with the jet stream and the tropopause, refer to chapter 19.

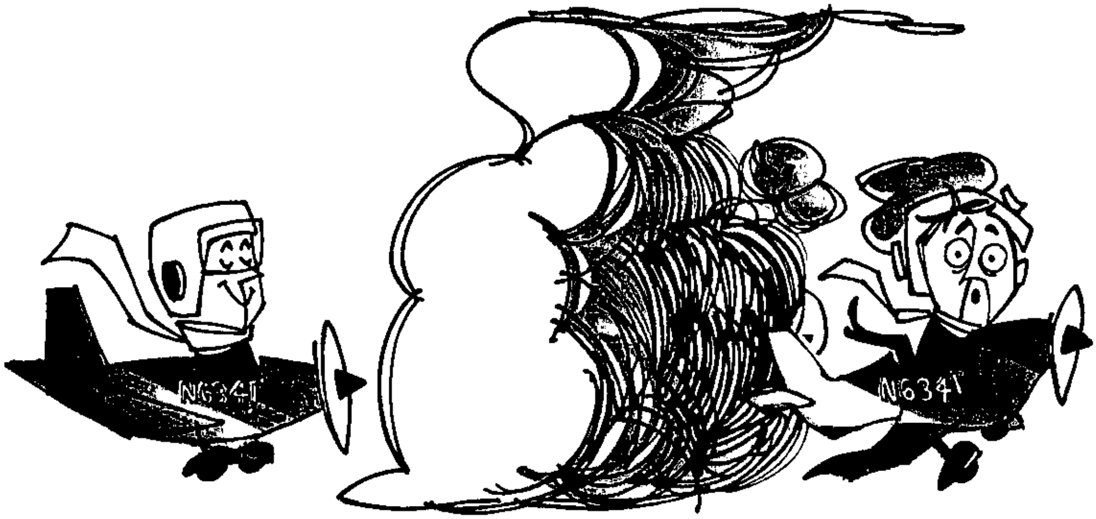
6. Where:
   a. Vertical wind shears exceed 6 knots per 1,000 feet, and/or
   b. Horizontal wind shears exceed 18 knots per 150 miles.

SEVERE TURBULENCE

1. In mountainous areas with a wind component exceeding 50 knots perpendicular to and near the level of the ridge:
   a. In 5,000-foot layers:
      (1) At and below the ridge level in rotor clouds or rotor action.
      (2) At the tropopause.
      (3) Sometimes at the base of other stable layers below the tropopause.
   b. Extending outward on the lee of the ridge for 50 to 150 miles.
2. In and near growing and mature thunderstorms.
3. Occasionally in other towering cumuliform clouds.
4. 50 to 100 miles on the cold side of the center of the jet stream, in troughs aloft, and in lows aloft where:
   a. Vertical wind shears exceed 6 knots per 1,000 feet, and
   b. Horizontal wind shears exceed 40 knots per 150 miles.

EXTREME TURBULENCE

1. In mountain wave situations, in and below the level of well-developed rotor clouds. Sometimes it extends to the ground.
2. In growing severe thunderstorms (most frequently in organized squall lines) indicated by:
   a. Large hailstones (3/4 inch or more in diameter),
   b. Strong radar echo gradients, or
   c. Almost continuous lightning.



Chapter 8
CLOUDS

Clouds are weather signposts in the sky. They indicate what the atmosphere is doing, giving visible evidence of the atmosphere's motions, water content, and degree of stability. In this sense, clouds are a friend to the pilot. They become his enemy, however, when they become too numerous or widespread, form at very low levels, or show extensive vertical development.

Knowledge of principal cloud types helps the pilot, when being briefed, to visualize expected weather conditions. His knowledge of cloud formations helps him to recognize potential weather hazards when he is flying.

Information on cloud types and amounts is received by the weatherman at frequent intervals. This is a very important aid to him in analyzing and predicting the weather.

CLOUD COMPOSITION

Chapter 5 indicated that clouds are composed of minute liquid water droplets and/or ice crystals, depending on the temperatures within them. When their temperature is between the freezing point (0° C.) and —15° C., they are composed largely of supercooled water droplets, but usually have some ice crystals. At temperatures below —15° C., clouds usually are composed entirely of ice crystals. However, supercooled droplets sometimes exist at temperatures as low as —60° C.

Cloud particles average about one-thousandth of an inch in diameter, but are clustered together enough to make them visible. They must grow enormously in order for precipitation to be produced; the average raindrop contains about one million times the water of that in a cloud droplet.

Condensation nuclei, such as dust and products of combustion, compose the centers of cloud particles. Chapter 5 indicated that these water-absorbent impurities must be present for cloud droplets or ice crystals to form when the air becomes saturated.

Clouds differ from fog only in that they do not reduce the horizontal visibility beneath them. In other words, fog is a cloud which lies at the earth's surface.

TYPES OF CLOUDS

The forms, species, and varieties of clouds are numerous enough to fill a book twice the size of this with illustrations and descriptions of each type. These many kinds of clouds are, however, internationally recognized. A detailed description of each type is available in the *International Cloud Atlas,* a publication of the World Meteorological Organization (WMO).

For the purpose of identification, pilots need to be concerned only with the more basic cloud types, which may be divided into four "families." These families are: high clouds, middle clouds, low clouds, and clouds with extensive vertical development. Within the high, middle, and low cloud families, there are generally two main subdivisions: (1) clouds formed when localized vertical currents carry moist air upward to the condensation level, and (2) clouds formed when whole layers of air are cooled until condensation takes place. The clouds in the first subdivision have a lumpy or billowy appearance and are called "cumulus type," meaning "accumulation" or "heap." Those in the second subdivision lie mostly in horizontal layers or sheets and, because of their appearance, are called "stratus type," meaning "spread out." In addition to these subdivisions, the word "nimbus," which means "raincloud," is added to the names of clouds that normally produce precipitation. Thus, a horizontal cloud from which rain is falling is called "nimbostratus"; a heavy and swelling cumulus that has grown into a thunderstorm is referred to as a "cumulonimbus." Clouds that are broken into fragments are usually identified by adding the suffix "fractus" to the classification name. For example, fragmentary cumulus clouds are referred to as "cumulus fractus."

CLOUD RECOGNITION

The following cloud photographs (figs. 41 through 50) and the descriptions under each will assist the pilot in recognizing the principal cloud types. Information of a nondescriptive nature is added when it is considered to be of significant value.

HIGH CLOUDS

The height of cloud bases ranges generally from 16,500 to 45,000 feet.

MIDDLE CLOUDS

The height of cloud bases ranges generally from 6,500 to 16,500 feet.

LOW CLOUDS

The height of cloud bases ranges generally from the surface to 6,500 feet.

CLOUDS WITH EXTENSIVE VERTICAL DEVELOPMENT

The height of cloud bases ranges generally from 1,000 to 10,000 feet.

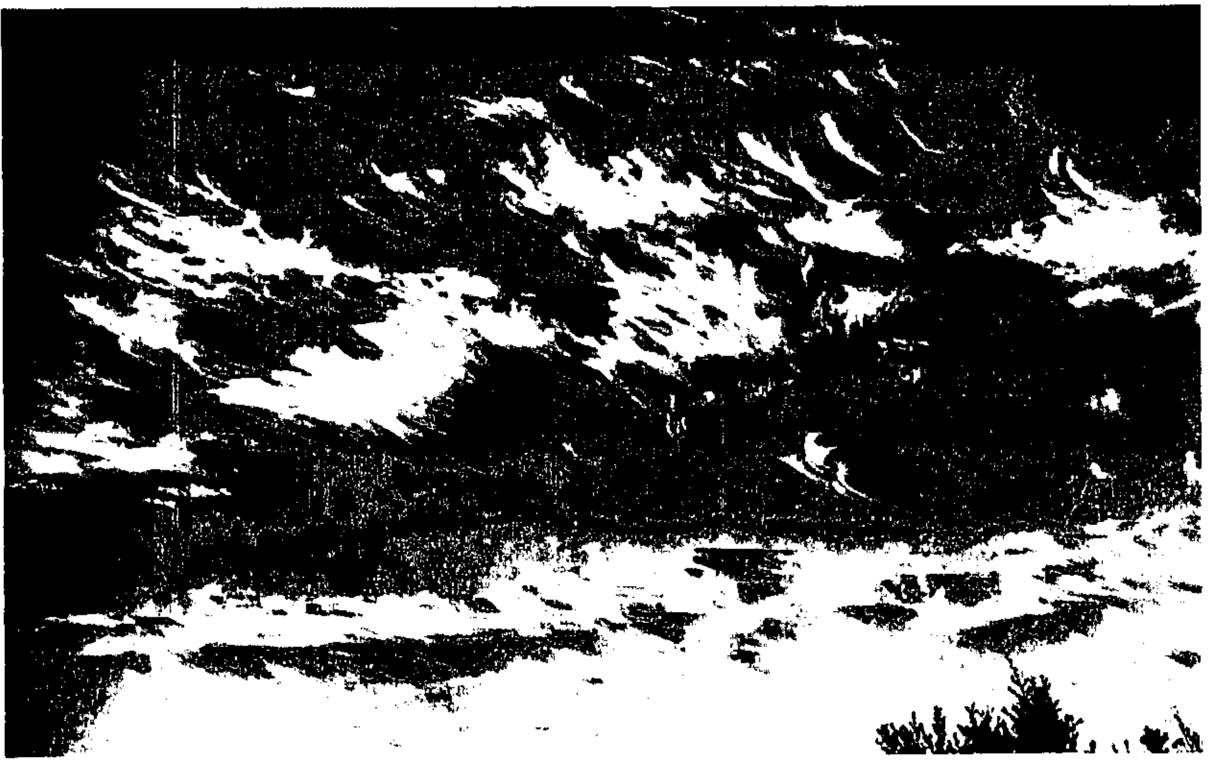


FIGURE 41. Cirrus: thin, white, featherlike clouds in patches or narrow bands; composed entirely of ice crystals of varying size; larger crystals often trail down a great vertical extent in well-defined wisps called "mare's tails."

FIGURE 42. Cirrocumulus: thin sheet of cloud with individual small white puffs appearing as flakes or patches of cotton; usually composed of ice crystals, but may be composed of highly supercooled water droplets, or a mixture of both; likely to be confused with altocumulus.

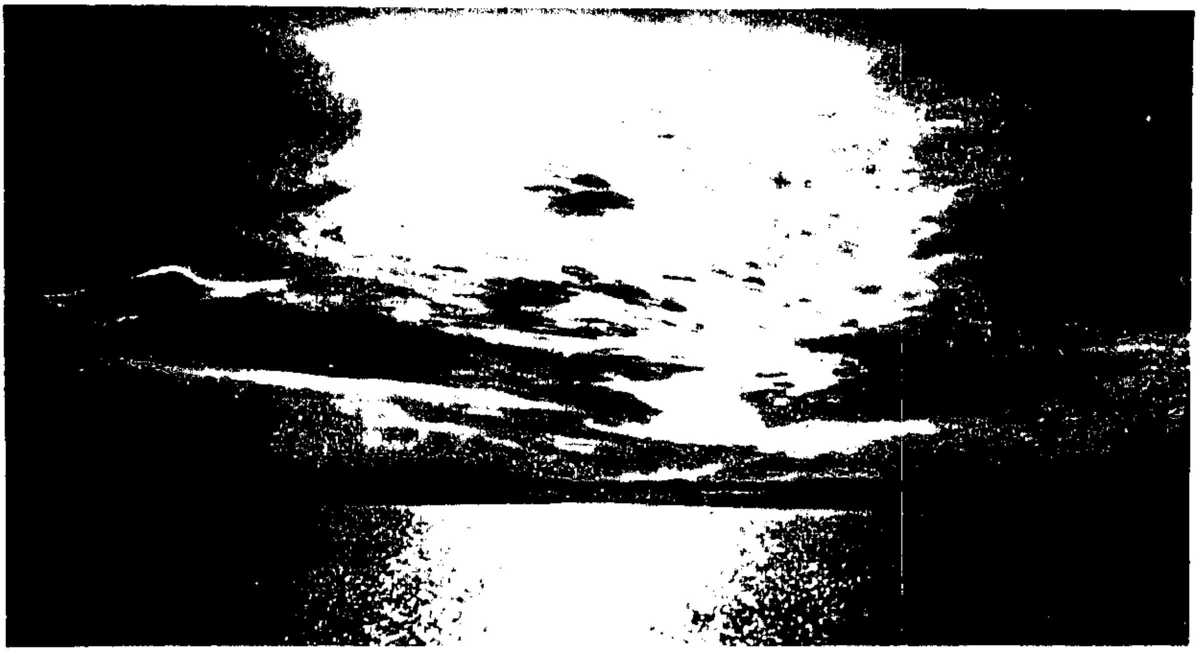


FIGURE 43. Cirrostratus: thin transparent, whitish cloud layer appearing as a sheet or veil; diffuse, or sometimes partly fibrous; generally produces halo phenomena.

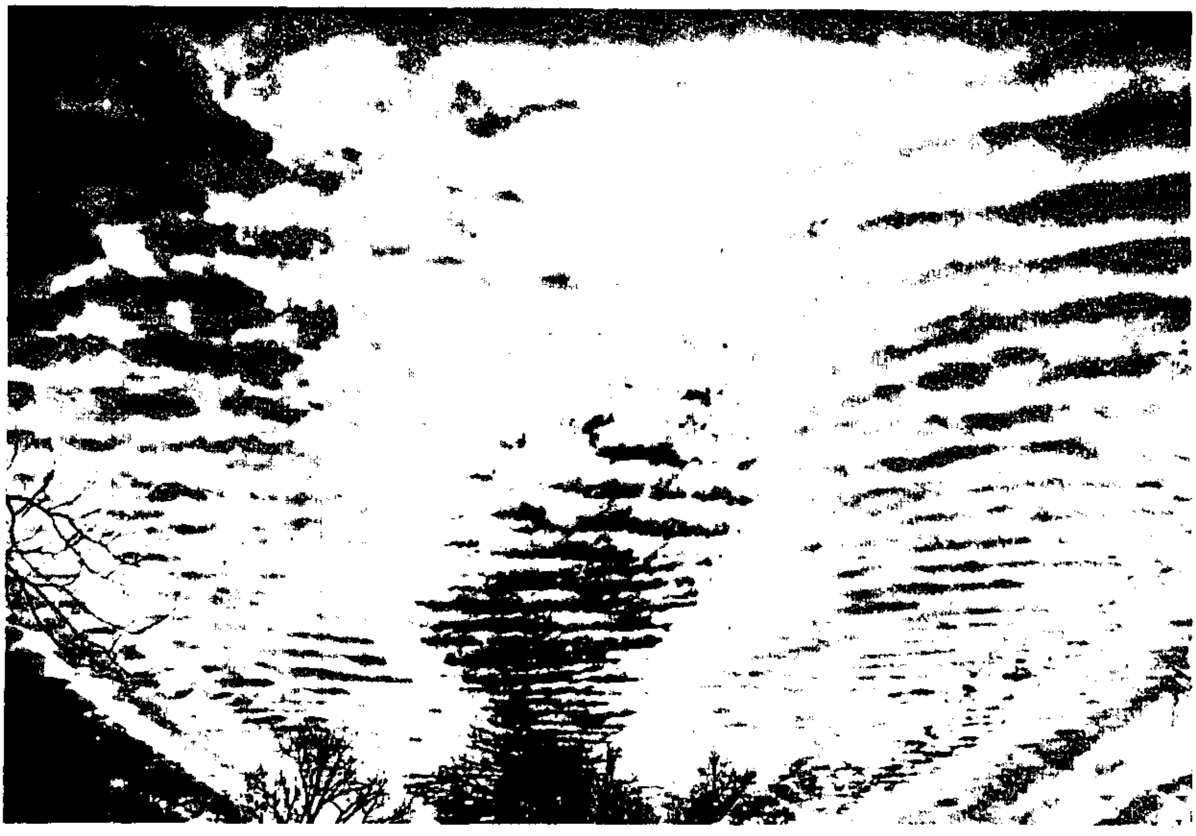


FIGURE 44. Altocumulus: white or gray layers or patches of solid cloud, often with a waved appearance; cloud elements appear as rounded masses or rolls; composed mostly of small liquid water droplets which are usually supercooled; at very low temperatures, ice crystals appear.

FIGURE 45. Altostratus: a gray or bluish veil or layer of cloud having a fibrous appearance; often associated with altocumulus; usually thinner than in this photograph and thin enough for the sun to be dimly visible; frequently composed of a mixture of supercooled water droplets and ice crystals; light, continuous precipitation often falls.

FIGURE 46. Nimbostratus: a gray or dark massive cloud layer, diffused by more or less continuous rain, snow or sleet; precipitation usually reaches the ground; composed of suspended water droplets, sometimes supercooled, and of falling raindrops and/or snowflakes.

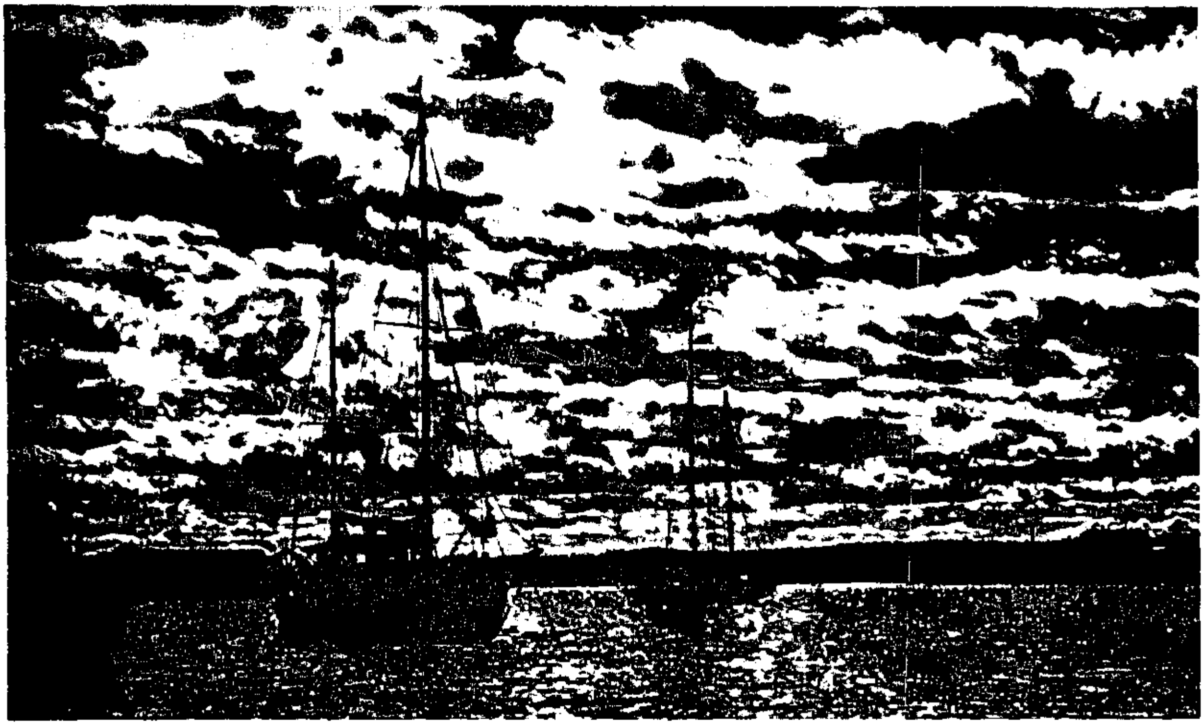


FIGURE 47. Stratocumulus: gray or bluish patches or layers with individual rolls or rounded masses; generally composed of small water droplets.

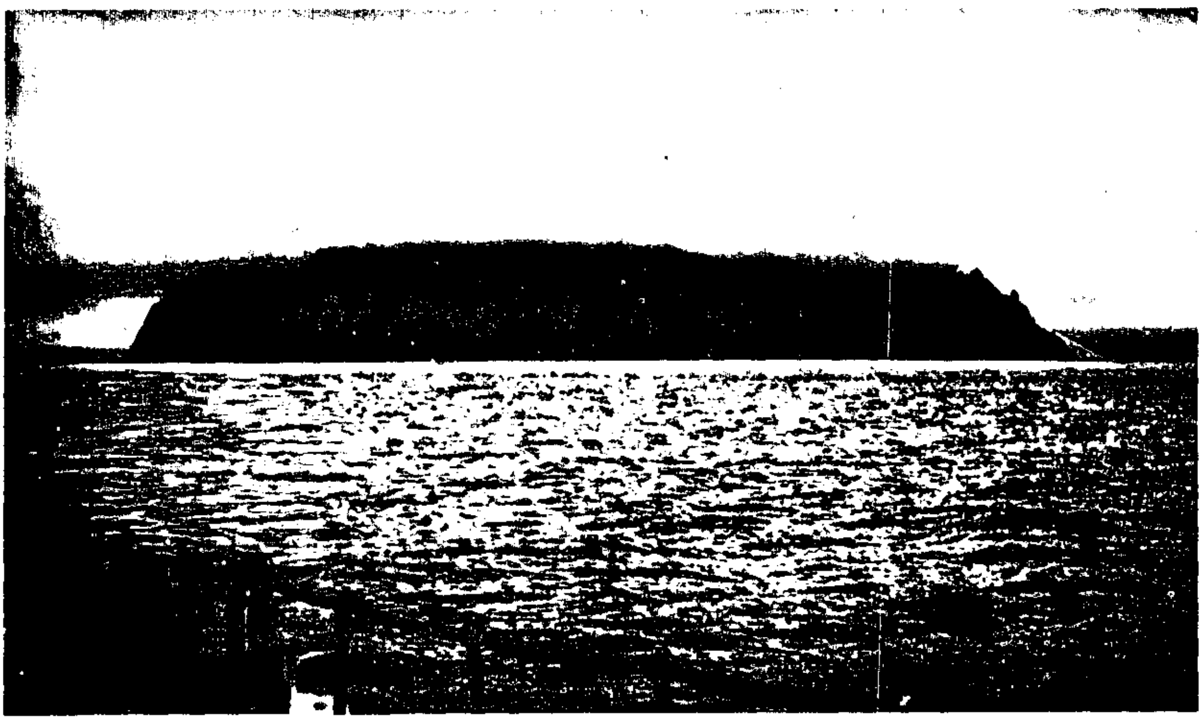


FIGURE 48. Stratus: low, gray cloud layer or sheet with a fairly uniform base; sometimes appears in ragged patches; usually does not produce precipitation, but occasionally may give drizzle or snow grains; often forms by evaporation or lifting of the lower layers of a fog bank; composed of minute water droplets, or if the temperature is low enough, partly of ice crystals; usually widespread horizontally.

FIGURE 49. Cumulus: detached domes or towers which are usually dense and well defined; develops vertically in the form of rising mounds of which the bulging upper part often resembles a cauliflower; often referred to by pilots as "cu" (pronounced "cue"); composed of a great density of small water droplets, frequently supercooled; larger drops often develop within the cloud and fall from the bases as trails of evaporating rain (virga); ice crystals sometime form in the upper portion and grow larger by taking water from the water droplets; maximum frequency and development in the afternoon over land and during the night over water.

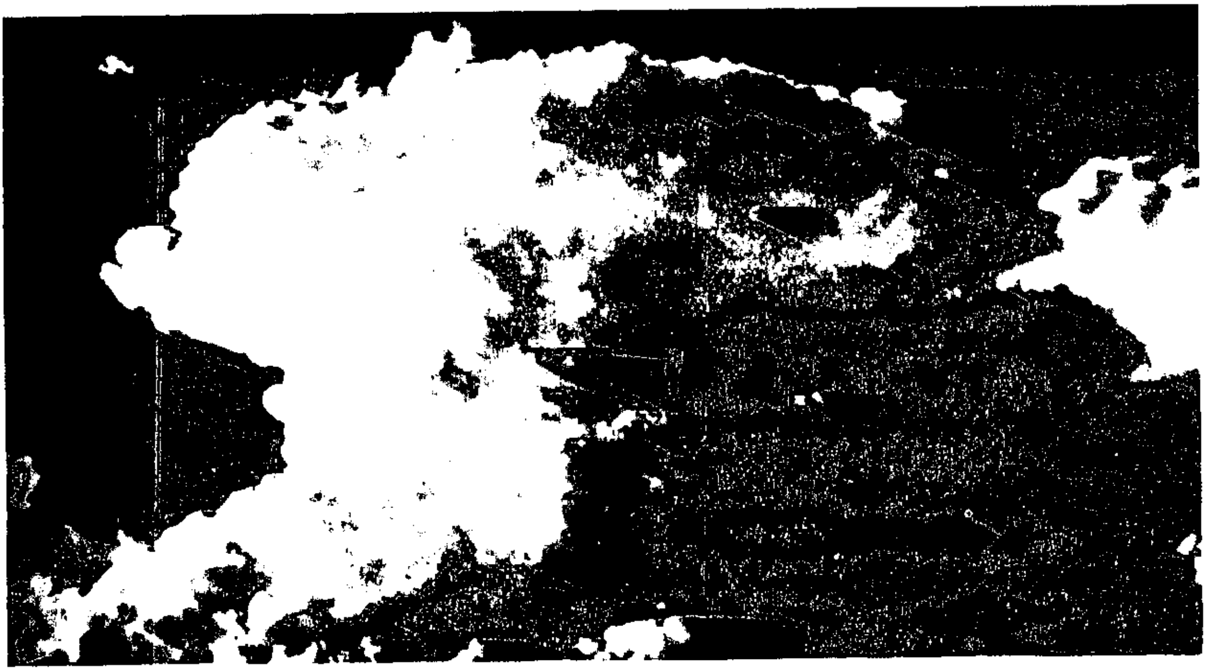


FIGURE 50. Cumulonimbus: heavy and dense cloud, with a considerable vertical extent, in the form of a mountain or a massive tower; often with tops in the shape of an anvil or vast plume; base of cloud often very dark with low ragged clouds either merged with it or not; frequently accompanied by lightning and thunder, and sometimes hail; occasionally produces a tornado or a waterspout; the ultimate manifestation of the growth of a cumulus cloud, occasionally extending well into the stratosphere; often referred to by pilots as "cb" (pronounced "sea bee").

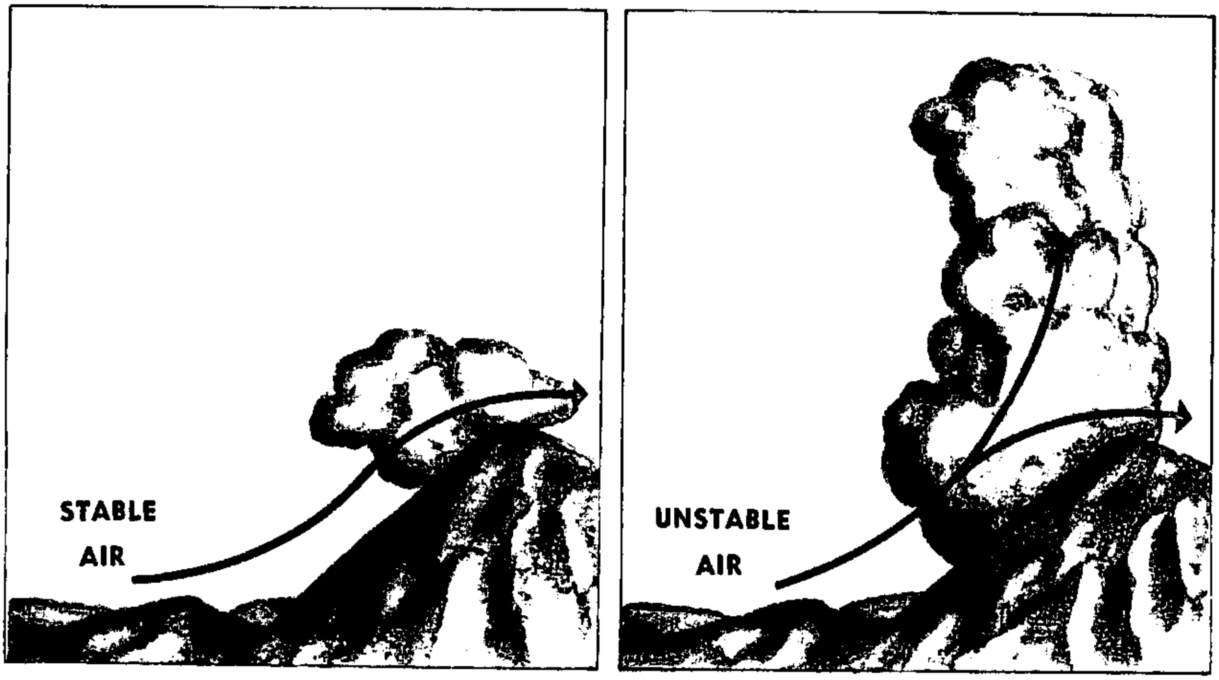


FIGURE 51. Cloud structure is determined by the air's degree of stability.

FIGURE 52. Stratus becoming stratocumulus and cumulus at a coast line.

CLOUD FORMATION AND STRUCTURE

As previously established, clouds form when water vapor condenses into visible droplets. Although on rare occasions the dew point temperature increases to the air temperature, the usual cause of condensation is cooling of the air to its dew point temperature. When the dew point and air temperature become the same, the air is saturated (relative humidity of 100 percent), and further cooling produces condensation. The cooling can take place (1) in localized vertical air currents produced by heating from below, or (2) through forced ascension of whole layers of air.

When clouds form, the degree of stability of the air helps determine what type they will be. Cumuliform clouds, because of associated vertical air currents, invariably have some degree of turbulence within them. Since there is little or no vertical motion within horizontal cloud layers, little if any turbulence is experienced within them.

When air is forced to ascend, the structure of any clouds which form depends almost entirely on the air's stability prior to the ascension. For example, very stable air being forced to ascend a mountain slope will remain sufficiently stable to prevent appreciable vertical development, and clouds will be layerlike with little or no turbulence (see fig. 51). If the air which is forced upward is initially unstable, however, the mountain slope will itself increase the tendency for vertical development, and cumuliform clouds may grow considerably (fig. 51).

Sometimes horizontal layers of clouds will change partly to cumuliform clouds as a result of heating from below. Forced ascension of an entire layer produces similar conditions if the air is conditionally unstable. This transition in cloud formation can sometimes be noted when flying over a relatively smooth cloud deck with cumuluslike clouds beginning to project upward. Sometimes these projections appear as only random puffs and at other times in groups or in lines. Lines of cumuliform clouds projecting upward out of a horizontal cloud deck sometimes indicate a frontal zone (the boundary between warm and cold air masses). A similar cloud pattern often occurs at a coastline (see fig. 52), a result of the temperature difference between the land and water. Mountain ranges, properly oriented relative to the flow of air, will produce lines of cumuliform clouds within what is otherwise a horizontal cloud layer.

Chapter 9
AIR MASSES

An air mass is a body of air extending over a large area (usually 1,000 miles or more across) with fairly uniform properties in a horizontal plane. That is, layer for layer, the air in one part of the air mass has about the same characteristics as the air in other parts of the same mass (see fig. 53). The basic properties of an air mass are described in terms of temperature and moisture, but general characteristics of flying weather conditions are also common to air mass types.

The weather over a location at a given time generally depends on either the character of the prevailing air mass, or the interaction of two or more air masses. Interaction of air masses is discussed in the next chapter. Except where this interaction is taking place, the weather is somewhat similar throughout an area covered by the same air mass, with variations caused by local geographical features such as mountains, valleys, and lakes.

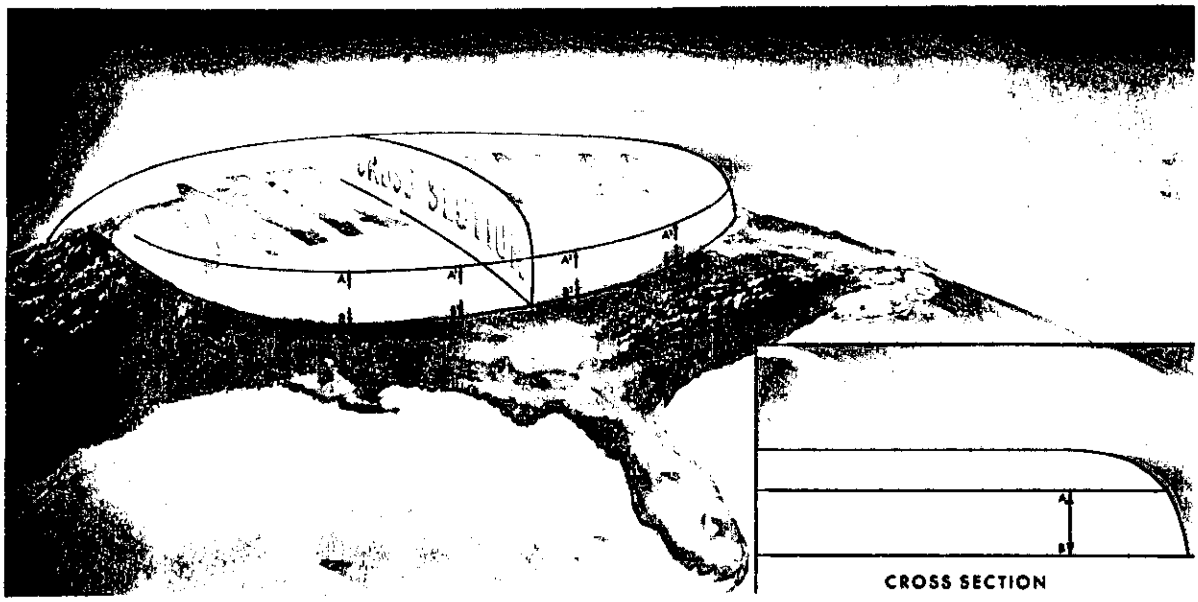


FIGURE 53. Horizontal uniformity of an air mass. (Properties of air at A¹, A², etc., are about the same as those at A; properties at B¹, B², etc., are about the same as those at B.)

SOURCE REGIONS

When a body of air comes to rest or moves very slowly over a land or sea area having fairly uniform properties of temperature and moisture, it tends to take on correspondingly uniform properties—the coldness of polar regions, the heat of the Tropics, the moisture of oceans, and the dryness of continents. For example, air stagnating during winter over northern Canada and the adjacent polar region becomes very cold and dry because the surface is covered with snow and ice. Later, as the air moves out of this region, it tends to remain cold and dry, although some modification will occur during its travel.

The region where an air mass acquired its identifying properties of temperature and moisture is called its "source region." The depth to which an air mass becomes modified by its source region depends upon (1) the length of time the air remains in the source region, and (2) the difference between the original temperature of the air and that of the underlying surface. When the air is initially colder than the temperature of the source region, it is heated from below. This produces ascending currents which carry the heat and moisture aloft, thereby modifying the air mass to a considerable height. On the other hand, when the air is initially warmer than the surface, it is cooled from below. This is a stable condition, and the air is modified to a lesser height because convective currents do not develop.

Air masses that form over a given source region vary in their properties of temperature and moisture from season to season, as the properties of the source region vary.

The best source regions for air masses are large snow or ice-covered polar regions, tropical oceans, and large desert areas. Midlatitudes, which have irregular surface features, are poor source regions. Air has little opportunity to stagnate in the midlatitudes, since weather and pressure patterns are on the move.

CLASSIFICATION OF AIR MASSES

Air masses are classified according to their source region. The two general source regions are polar (designated as P) and tropical (designated as T). The underlying surface in the source region is either maritime (water) or continental (land), and is designated as "m" or "c" preceding the P or T. Thus, the four basic types of air masses are designated mP, mT, cP, or cT, according to their source region. It is natural that air, after lying for a long time over a polar region, will become cold, or after lying over a tropical region, will become warm. It is also natural that air lingering over a water area will become moist (at least in its lower layers), and that air lingering over land will become dry. The four basic air mass types, therefore, are often referred to as "moist cold," "moist warm," "dry cold," or "dry warm." Typical paths taken by air masses entering the contiguous United States are shown in figure 54.

A third letter follows the P or T to indicate whether the air is colder (k) than the surface over which it is moving, or warmer (w) than the surface over which it is moving. The "k" type air mass will be warmed from below, and convective currents will form. Some typical characteristics of the "k" type air mass are (1) turbulence up to about 10,000 feet, (2) an unstable lapse rate (nearly dry adiabatic), (3) good visibility, except in showers and dust

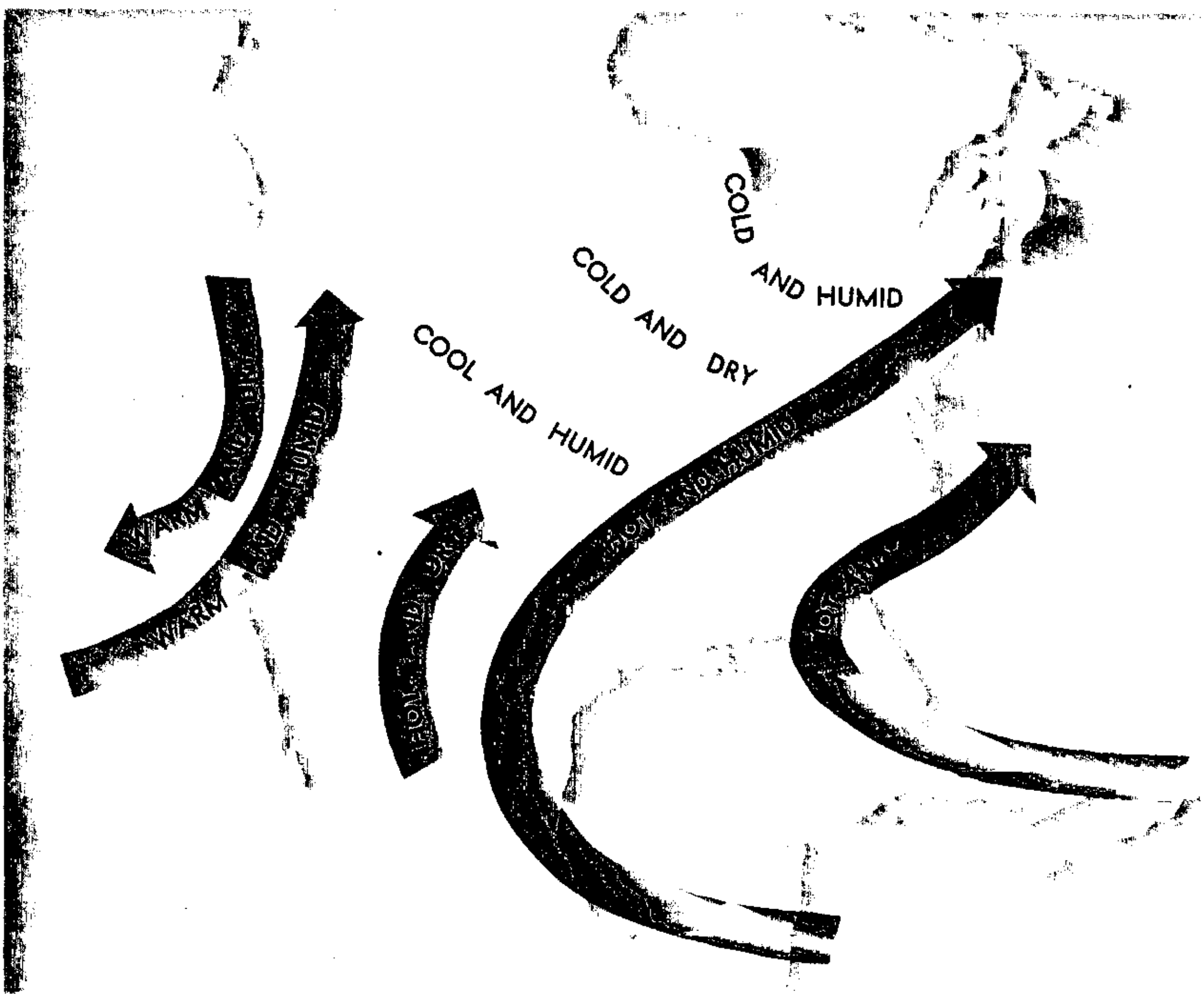


FIGURE 54. Typical paths of air masses. Note the FOEHN effect in the western United States.

storms, (4) cumuliform clouds, and (5) showers, thunderstorms, hail, sleet, and snow flurries.

The "w" type of air mass, being cooled from below, exhibits different characteristics. This type tends to maintain its original properties and is modified only in the lower few thousand feet as it moves. Some typical characteristics are (1) smooth air (above the friction level), (2) a stable lapse rate, (3) poor visibility (smoke and dust are held in the lower few thousand feet), (4) stratiform clouds and fog, and (5) drizzle.

Air mass types often are designated on weather charts prepared at the local weather station.

AIR MASS MODIFICATION

Just as an air mass tends to take on the temperature and moisture properties of its source region, it also tends to have these properties changed when it moves out of its source region. The degree of modification of an air mass is dependent on (1) the speed with which it travels, (2) the nature of the region it moves over, and (3) the temperature difference between the new surface and the air mass.

The ways in which various atmospheric processes modify an air mass should be considered before we deal with the average weather conditions associated with each air mass type. For the most part, this is a review of principles previously discussed. Keep in mind that more than one of these processes is usually in progress at the same time.

Warming from below, which decreases the stability of the air mass, may result from (1) the horizontal movement (advection) of a cold air mass over a warmer surface, or (2) heating of the surface under the air mass by the sun.

Cooling from below, which increases the stability of the air mass, may result from (1) the advection of a warm air mass over a colder surface, or (2) radiational cooling of the surface under the air mass.

An addition of water vapor to the lower layers of an air mass, decreases its stability. Moisture is added by (1) evaporation from water surfaces, moist ground, and liquid precipitation, or (2) sublimation from ice or snow surfaces and solid precipitation.

Removal of water vapor from the lower layers of an air mass, increases its stability. Moisture is removed by (1) condensation, (2) sublimation, or (3) precipitation.

Lifting of the air mass decreases its stability. Lifting may be produced (1) by the air being warmed from below, (2) by air being forced up the slopes of mountains (orographic lifting), or (3) in the warm air mass when it is forced over colder air (ch. 10). Ascending currents result in expansion and cooling of the air mass. Cooling increases the relative humidity and, if the amount of cooling is sufficient, the air becomes saturated. Clouds form when the air becomes saturated, and precipitation may or may not result, depending on additional factors.

Sinking of the air mass increases its stability. Descending currents are present if (1) air is forced down from above a colder air mass, or (2) air moves from mountains to lowlands. Air may also sink and spread out as a result of its own weight (subsidence). The relative humidity of descending air decreases due to warming of the air as it is compressed. For this reason, clouds usually dissipate in descending air currents.

It will also be helpful in the study of *average* weather conditions found in each type of air mass to make the following distinction between conditions typically associated with unstable air and those typically associated with stable air:

UNSTABLE AIR	STABLE AIR
Cumuliform Clouds	Stratiform Clouds and Fog
Showery Precipitation	Continuous Precipitation
Rough Air (Turbulence)	Smooth Air
Good Visibility, Except in Blowing Sand and Snow	Fair to Poor Visibility

AIR MASS WEATHER IN WINTER

CONTINENTAL POLAR (cP)

Air masses that stagnate in the continental polar regions above the 50th parallel in winter become very cold. The effect of cooling, however, seldom extends in depth to above 10,000 feet.

Figure 55 illustrates some of the paths taken by cP air entering the contiguous United States. Path No. 1 is usually indicative of a strong outbreak of cold air accompanied in the lower few thousand feet by high winds with rough and gusty flying conditions. A strong inversion persists between 5,000 and 10,000 feet, and fractocumulus and stratocumulus clouds often form underneath this inversion. As the air mass following this path moves over the Great Lakes, it is heated from below, and moisture is added, especially during early winter before the Lakes are frozen over. This results in either rain or snow showers on the lee side of the Lakes, and

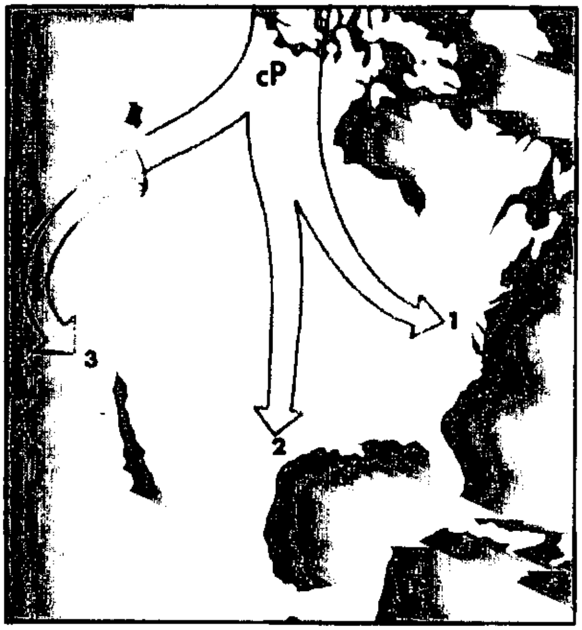


FIGURE 55. Paths of cP air.

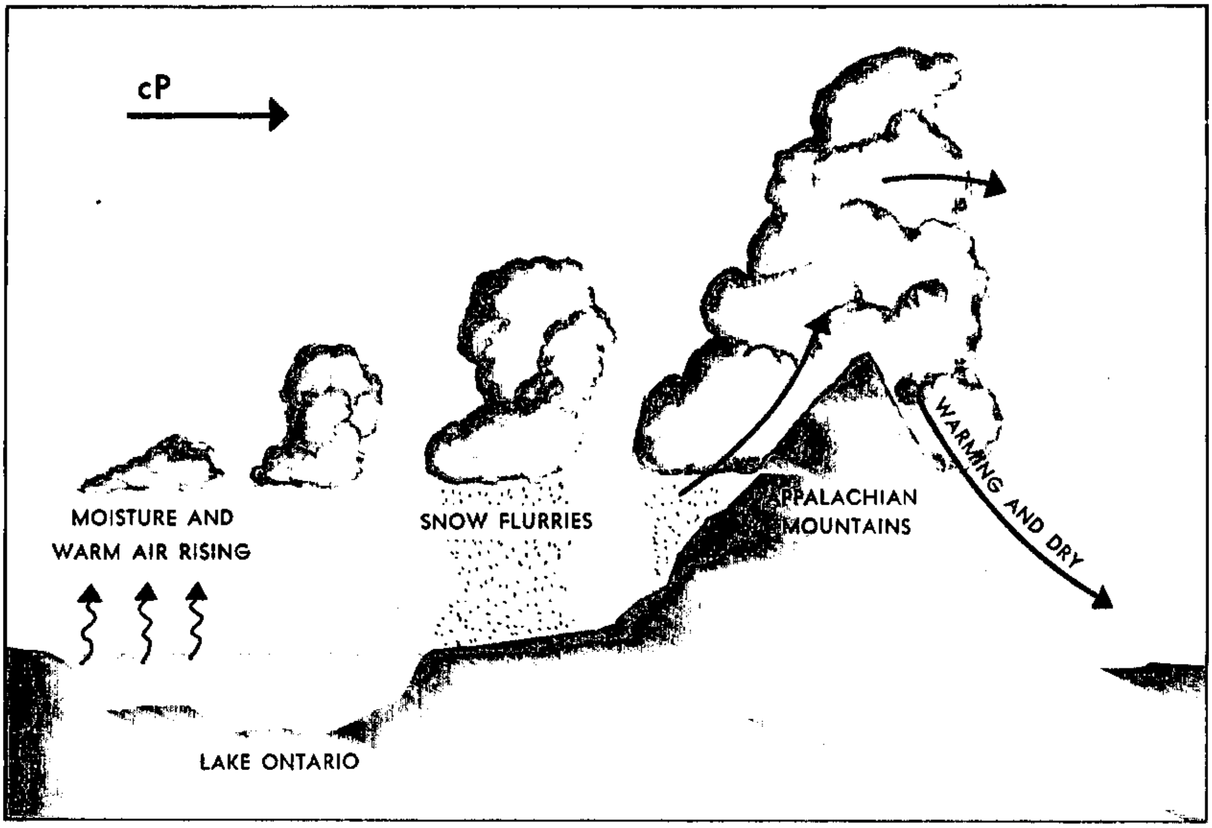


FIGURE 56. A cP air mass moving across the Great Lakes.

on the windward side of the Appalachian Mountains (see fig. 56). Clouds on the lee side of the Lakes have bases at 500 to 1,000 feet. Cloud tops generally are at about 8,000 feet, but snow flurry clouds sometimes extend to about 12,000 feet. Over the mountains, cloud bases are near or on the ground, and tops extend upward to about 14,000 feet.

East of the mountains, relatively clear skies prevail. In the Middle West, clouds associated with a cP air mass continue for 24 to 48 hours after its arrival, while along the Atlantic Coast, rapid passage of the leading edge of this type of air mass produces almost immediate clearing.

When polar air follows Path No. 2 (fig. 55), flying conditions over the central United States are generally smooth, except within the lower 4,000 feet. Here, contact of the air with the warmer surface may cause turbulence. Surface visibility becomes poor if the air mass stagnates. At these times, subsidence aloft causes a temperature inversion which traps haze, smoke, and dust in the lower layers (see fig. 57), but visibility improves during the day as the sun heats the earth's surface and adjacent air. This decreases the stability of the lower layers and may completely eliminate the inversion. Surface visibility is usually good at all times when the air mass is on the move.

The West Coast States are invaded by very cold, convectively unstable air when the continental polar air mass follows Path No. 3 (fig. 55). This does not occur very frequently, but the western area of the United States receives its coldest weather when it does. Showers are numerous, and, at times, the air is cold enough for snowfall as far south as southern California.

The Pacific Northwest often is invaded in winter by an air mass originating in the very cold region of northern Asia. Its path of

FIGURE 57. Top of haze layer as seen from an airborne glider (courtesy Jack P. Perine, Mid-Atlantic Soaring Association).

movement (see fig. 58) usually takes it over a portion of the ice-covered Arctic Ocean, then southeastward across Alaska and the Gulf of Alaska. The air mass remains more continental than maritime in character, bringing very cold weather to the Pacific Northwest. The distance that the air mass moves over water is short, relative to the total distance of its travel, and the movement of the air mass is usually rapid. These factors tend to minimize modification by the comparatively warm waters of the Gulf of Alaska. However, there is sufficient warming from below to make the air very unstable, and enough moisture is added to produce the showers and squalls which result when the air is lifted over the coastal ranges. Showers are often heavy, but have a short life. Ceilings are commonly about 2,000 feet along the coast and near zero over mountain ranges. The visibility is good except in precipitation.

MARITIME POLAR (mP)

Maritime polar (mP) air from over the Pacific Ocean dominates the west coast of the United States during winter months. When there is rapid west-east motion and small north-south motion of pressure systems, mP air may influence the weather over most of the United States. The long over-water trajectory results in heating to a considerable height, and the air is convectively unstable up to about 10,000 feet, with high relative humidity. The air has typical "k" type characteristics—turbulence, gusty winds, a steep lapse rate, good visibility at the ground except in precipitation, and cumulus and cumulonimbus clouds with showers.

Maritime polar air sometimes stagnates between the mountains in the Great Basin region of the western United States. Subsidence inversions, low stratus clouds, and fog form, sometimes persisting for a week or more and causing the Pacific Coast valleys to be among the foggiest places in the country during winter. When this air moves eastward across the Continental Divide and downslope, it generally brings clear skies, mild temperatures, and low humidities.

Maritime polar air that drifts eastward without stagnating has much of its moisture condensed out during the lifting necessary to cross

FIGURE 58. Path of cP air from Northern Asia.

the mountains. Then it warms as it descends, forming a very stable air mass with good flying conditions (see fig. 59). This air has large daily temperature ranges. If, however, instead of being allowed to descend on the east side of the mountains, the air is forced aloft over a deep dome of cold air, a very severe snowstorm may occur.

Atlantic mP air appearing on the east coast usually is formed by an overwater trajectory of cP air. Also, Atlantic mP air on the east coast typically is found adjacent to mT air. The meeting of these two air masses results in thick cloud decks, low ceilings, freezing rain and sleet, and poor visibility, especially from the coast westward to the Appalachians.

MARITIME TROPICAL (mT)

Two distinct maritime tropical air masses are found in North America in winter. One originates in the Pacific high pressure system between California and Hawaii. The other has two source regions, one in the Gulf of Mexico and the Caribbean Sea, and the other in the

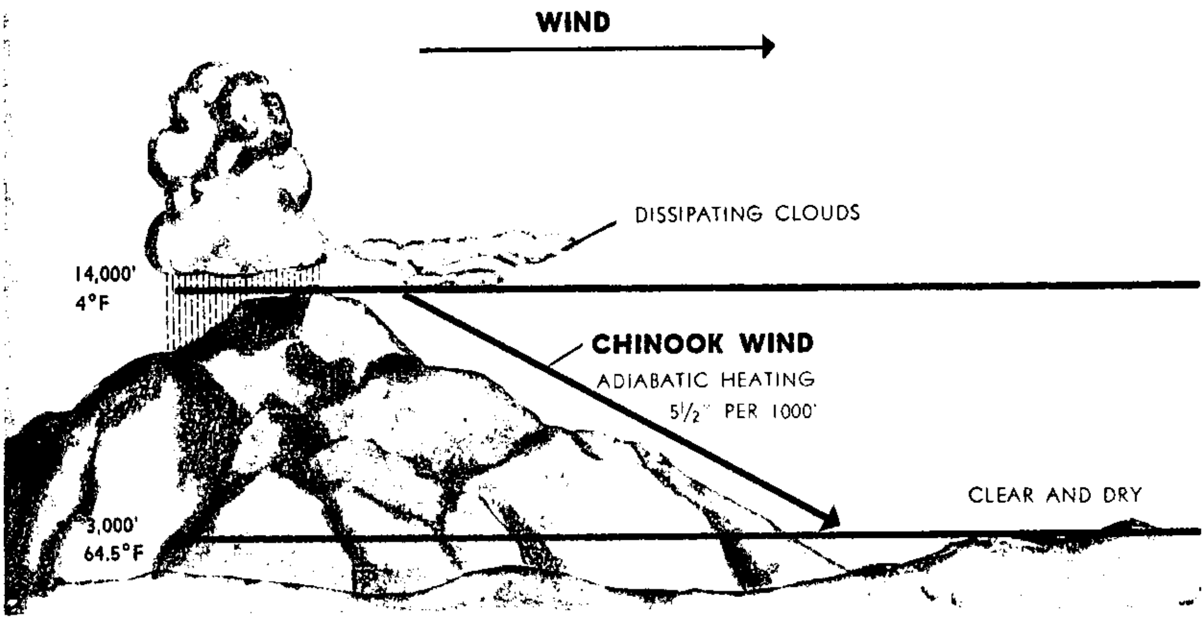


FIGURE 59. Changes in an air mass by passing over a mountainous barrier.

Sargasso Sea in the western Atlantic Ocean. The Atlantic mT air masses have essentially the same properties despite the two different source regions and they play significant roles in the central and eastern United States. In its source region mT air is characterized by high temperatures, high moisture content, conditional instability, good visibility, and a few stratus or stratocumulus clouds. This air is relatively dry above 10,000 feet.

The Bermuda High, the semipermanent high pressure system in the Atlantic Ocean, largely influences the movement of mT air masses into the United States. This high pressure system meanders considerably, and the speed with which mT air masses move into the southeastern and Gulf Coast States depends upon the strength and specific location of the Bermuda High at the time.

Maritime tropical (mT) air masses moving inland during the winter tend to become very stable in the lower layers because the land is colder than the water. This is especially true at night when the earth's surface and overlying air are not heated by the sun. The extent to which the low clouds and fog spread inland depends on (1) the strength of the onshore winds, and (2) the difference between the temperature of the air and the temperature of the ground. On occasion, when the land temperatures are extremely cold, an extensive surface temperature inversion develops. Under this condition, daytime heating usually does not eliminate the inversion, and the fog and stratus may persist for several days.

When mT air moves far enough inland so that it is lifted up the slope of extensive mountain ranges, such as the Appalachians, it becomes unstable. Heavy cumulus and stratocumulus clouds develop, and the mountain tops usually become obscured.

Wintertime mT air masses seldom reach the northern and northeastern United States. The exception is found when low pressure systems move from the southern United States in a northerly direction. Southerly winds on the east side of these lows then transport mT air to latitudes where polar air masses are normally dominant.

Pacific mT air does not enter the contiguous United States very often; when it does, it is usually brought in with a low pressure system in California. The air is then rapidly forced aloft by the mountains, causing extensive cloudiness and very heavy precipitation in southern California.

Maritime tropical (mT) air masses have more moisture than any other air masses entering the United States. Thus, they are responsible for a greater portion of precipitation in North America, both winter and summer, than are other air masses. Precipitation is usually very heavy when mT air is interacting with polar air masses, and is heavier when the polar air is of continental origin, due to the greater temperature contrast between the air masses. Precipitation is often of long duration when this interaction takes place. This will be better understood after a study of "fronts", the subject of the next chapter.

AIR MASS WEATHER IN SUMMER

CONTINENTAL POLAR (cP)

Because of the extremely long days and the absence of a snow cover over a large portion of their source region, the cP air masses in summer are very different from those observed during the winter months. The warmth of the underlying surface produces unstable layers near the ground, in contrast to the extremely stable conditions arising during the winter.

Since the general atmospheric circulation is weaker during the warmer portion of the year, polar outbreaks move more slowly than in winter. Therefore, the air undergoes tremendous changes in passing slowly from its source region to the southern United States.

Continental polar (cP) air masses are relatively cool, but surface temperatures vary widely from night to day due to dryness of the air. During afternoon hours, adiabatic or superadiabatic lapse rates may develop near the ground and produce turbulence up to 6,000 or 8,000 feet. As in winter, this air mass usually has very few clouds. However, cP air in summer is sometimes so warm that it is cooled from below when moving over the Great Lakes. In this situation, the increased stability in the lower layers often results in fog and low stratus over and to the lee of the Lakes. Occasionally, cP air stagnates for a few days over the southeastern United States and accumulates sufficient moisture to produce isolated thundershowers, which usually are confined to the mountains.

MARITIME POLAR (mP); PACIFIC COAST

Summertime maritime polar air masses are more stable than those of wintertime. When these air masses approach the western United States, very persistent sea fogs which seriously hamper aircraft operations develop near and along the California coast. Although the mP air is fairly cool, it is further cooled from below by a relatively cold water belt which is found along the coast during summer. Sometimes the sea fog lifts to become a deck of stratus clouds before arriving at coastal stations. The fog-formed low stratus has bases ranging from less than 500 feet to about 1,500 feet and tops at usually less than 3,500 feet.

As the mP air moves inland and lifts along the western slopes of the mountains, it produces unstable conditions usually resulting in development of cumuliform clouds. Daytime surface heating intensifies the cloud development. However, most of the water vapor in the air mass is consumed by the formation of these clouds, and little if any precipitation occurs, except occasionally in the high Sierra Nevada. When the air passes over the eastern slopes of the Rockies, it is heated by compression as it descends, and the relative humidity decreases to a low value. This results in clear dry weather in the air mass as it moves into the eastern part of the country.

MARITIME POLAR (mP); ATLANTIC COAST

In summer, the Atlantic mP source region is the colder waters of the North Atlantic Ocean which may actually be colder than the cP source region. Moving southward, this air brings cooling to stations along the Atlantic sometimes as far south as Florida. The most significant effect on flight operations is the stratus cloud layer which forms along and near the coast, but this stratus deck presents no serious problem for pilots except when a low pressure system develops off the coast. At these times, the base of the cloud layer usually drops to a few hundred feet with drizzle, and fog often forms. In the absence of cyclonic activity, the stratus deck is usually based at 1,000 to 1,500 feet, with tops at about 3,000 feet.

MARITIME TROPICAL (mT)

Tropical air masses originating in the Pacific Ocean play an insignificant role in summer. On the other hand, maritime tropical air masses with source regions in the Gulf of Mexico and the Atlantic are even more important in summer than in winter as far as the weather of the central and eastern United States is concerned. Even the weather of the southwestern United States is frequently affected by mT air from the Gulf. There is almost a continuous movement of tropical maritime air over the central and eastern United States in summer, causing oppressive heat and humidity. This air often moves as far north as southern Canada.

Since the source region properties of maritime tropical air in summer are warmer and more moist than in winter, convective instability extends to higher levels. Stratocumulus clouds with bases at about 1,000 feet often form during the night over the southern coastal States. These clouds usually change during the late morning to scattered cumulus with bases at 3,000 to 4,000 feet. They continue to grow in size and number, frequently developing into extensive thunderstorms by late afternoon. Thunderstorms usually are widely scattered but, in mountainous areas, are more numerous and more intense.

CONTINENTAL TROPICAL (cT)

The only source regions for cT air over North America are Mexico and the Great Basin area of western United States. In summer, this very warm and dry air, often called "Superior," sometimes spreads eastward and northward from its source region to cover a large portion of the central and western United States. Technically, this air does not have a

Air Mass	Clouds	Ceilings	Visibilities	Turbulence	Surface Temp. Degrees F.
cP (near source region).	None	Unlimited	Excellent (except near industrial areas, then 1–4 miles).	Smooth except with high wind velocities.	–10 to –60.
cP (southeast of Great Lakes).	Stratocumulus and cumulus tops 7,000–10,000 feet.	500–1,000 feet, 0 over mountains.	1–5 miles, 0 in snow flurries.	Moderate turbulence up to 10,000 feet.	0 to 20.
mP (on Pacific coast).	Cumulus tops above 20,000 feet.	1,000–3,000 feet, 0 over mountains.	Good except 0 over mountains and in showers.	Moderate to severe turbulence.	45 to 55.
mP (east of Rockies).	None	Unlimited	Excellent except near industrial areas, then 1–4 miles.	Smooth except in lower levels with high winds.	30 to 40.
mP (east coast).	Stratocumulus and stratus tops, 6,000–8,000 feet.	0–1,000 feet	Fair except 0 in precipitation area.	Rough in lower levels	30 to 40.
mT (Pacific coast).	Stratus or stratocumulus.	500–1,500 feet	Good	Smooth	55 to 60.
mT (east of Rockies).	do	100–1,500 feet	do	do	60 to 70.

FIGURE 60. Winter flying weather conditions in various air mass types.

surface source. It is air from aloft that has subsided (sunk), sometimes reaching the surface. Mexico and the Great Basin are favorable areas for Superior air because there is very little movement of wind over that region, especially in summer.

Since humidities in cT air are very low, cloudiness is sparse. When present, clouds are of the cumuliform type and are found mainly over the mountains. Their bases are exceptionally high for cumulus clouds, 10,000 or 11,000 feet instead of the more usual bases of 3,000 to 5,000 feet. Flying is often rough at middle and low levels, especially during daylight hours when surface heating is contributing to the air's instability. Occasional dust storms present another significant hazard to flying because dust may extend to high altitudes and reduce visibilities for extended periods.

A brief summary of characteristic flying weather conditions in the various types of air masses is given in figures 60 and 61.

Air Mass	Clouds	Ceilings	Visibilities	Turbulence	Surface Temp. Degrees F.
cP (near source region).	Scattered cumulus	Unlimited	Good	Moderate turbulence up to 10,000 feet.	55–60.
mP (Pacific coast).	Stratus tops, 2,000–5,000 feet	100 feet–1,500 feet	1/2–10 miles	Slightly rough in clouds. Smooth above.	50–60.
mP (east of Pacific).	None except scattered cumulus near mountains.	Unlimited	Excellent	Generally smooth except over desert regions in afternoon.	60–70.
S (Mississippi Valley).	None	do	do	Slightly rough up to 15,000 feet.	75–85.
mT (east of Rockies).	Stratocumulus early morning; cumulonimbus afternoon.	500–1,500 feet a.m.; 3,000–4,000 feet p.m.	do	Smooth except in thunderstorms, then severe turbulence.	75–85.

FIGURE 61. Summer flying weather conditions in various air mass types.

Chapter 10
FRONTS

Since polar air masses have properties which usually are so much different from the air masses originating in the Tropics, it is obvious that, with their paths of movement, they must "clash" with each other somewhere, just as opposing military ground forces clash in a war. These air masses cover many thousands of square miles, and therefore the "battlefront" at which they meet is hundreds of miles long. Just as a battlefront is really a battle zone rather than a sharp wall, as the term "front" may imply, air masses come together in a zone of transition, often referred to as a frontal zone or zone of discontinuity. Frontal zones, normally many miles in width, are narrowest when the air masses have vastly different properties and have a tendency to blow toward one another. A frontal zone, customarily called a "front," is indicated on a surface weather chart by a line. With the limited number of stations to report weather, usually it is impossible to determine the exact outer boundaries of the frontal zone. Many times, fronts over ocean areas must be located on the basis of very sparse data. Cloud pictures from weather satellites are helpful in filling data gaps in some of these cases. Weather satellites will be discussed in a later chapter.

Fronts are especially important to pilots because many weather hazards to aviation may accompany them. Weather hazards, of course, are not limited to frontal zones. Later in the chapter it will be seen that some fronts do not produce clouds and precipitation. In addition, weather associated with one section of a front is frequently different from the weather in other sections of the same front.

FRONTAL STRUCTURE

The study of air masses revealed that bodies of air take on the properties of their source regions first at the surface level. These properties then work gradually upward in the mass, modifying it less and less as height increases. From this process, two things become evident: (1) Since air masses have depth, the zone of transition between them exists not only at the surface but for a considerable depth upward from the surface as well; and (2) Since air masses acquire the properties of their source regions to the greatest degree at and near the surface, the contrast between air masses is most significant in the lower atmospheric layers. At some level above the surface, depending on the height to which the individual air masses are modified appreciably by their source regions, the difference between the two air masses becomes quite small. Most fronts are not recognizable above 15,000 to 20,000 feet as far as cloud and precipitation patterns are concerned. However, the temperature contrast between the air masses in some cases may extend upward to the tropopause.

Since the air masses separated by a front have different properties of temperature and moisture, they also have different densities. Cold air masses are heavier than warm ones. When the warm air mass has slow movement compared to that of the cold air mass approaching it, the heavy, cold air rushes in and wedges underneath the lighter, warm air. Surface friction tends to hold back the air in contact with the earth's surface, creating a bulge in the front. This also tends to give the front a steep slope, especially at low levels. Conversely, when the cold air mass has slow movement relative to the warm air mass approaching it, the warm, light air slides up over the cold, heavier air. The resulting slope of the frontal surface is shallower and smoother in this situation.

The frontal slope tends to be shallow when there is a small difference in wind speed between the contrasting air masses and steep when the wind speed difference is large.

THE POLAR FRONT

The middle latitudes is the favored "battleground" of the cold air masses which dominate the polar regions and the warm ones which dominate the Tropics. They are continually interacting with each other—the cold air pushing southward and the warm air moving northward, in alternating tongues or waves. The zone which separates these air masses is called the "polar front."

The polar front is not stationary. At places, a strong flow of cold air pushes southward and replaces the warm tropical air. At other places, it retreats ahead of the advancing tropical air. *While the front is advancing southward in one region, it usually is advancing northward in an adjacent region.* This gives the front a wave-like shape, as shown in figure 62. It must be emphasized that the semipermanent polar front will seldom be found as a continuous zone encircling the entire hemisphere as illustrated. There are almost always some places around the hemisphere where the transition between the polar and tropical air masses is so gradual that there is no distinguishable boundary separating them. The front, therefore, has breaks in it. Breaks are apt to be more numerous in summer when the entire front is generally less distinct. The polar front, usually located in the temperate zone (midlatitudes), frequently moves well into the Tropics in winter; cold air masses

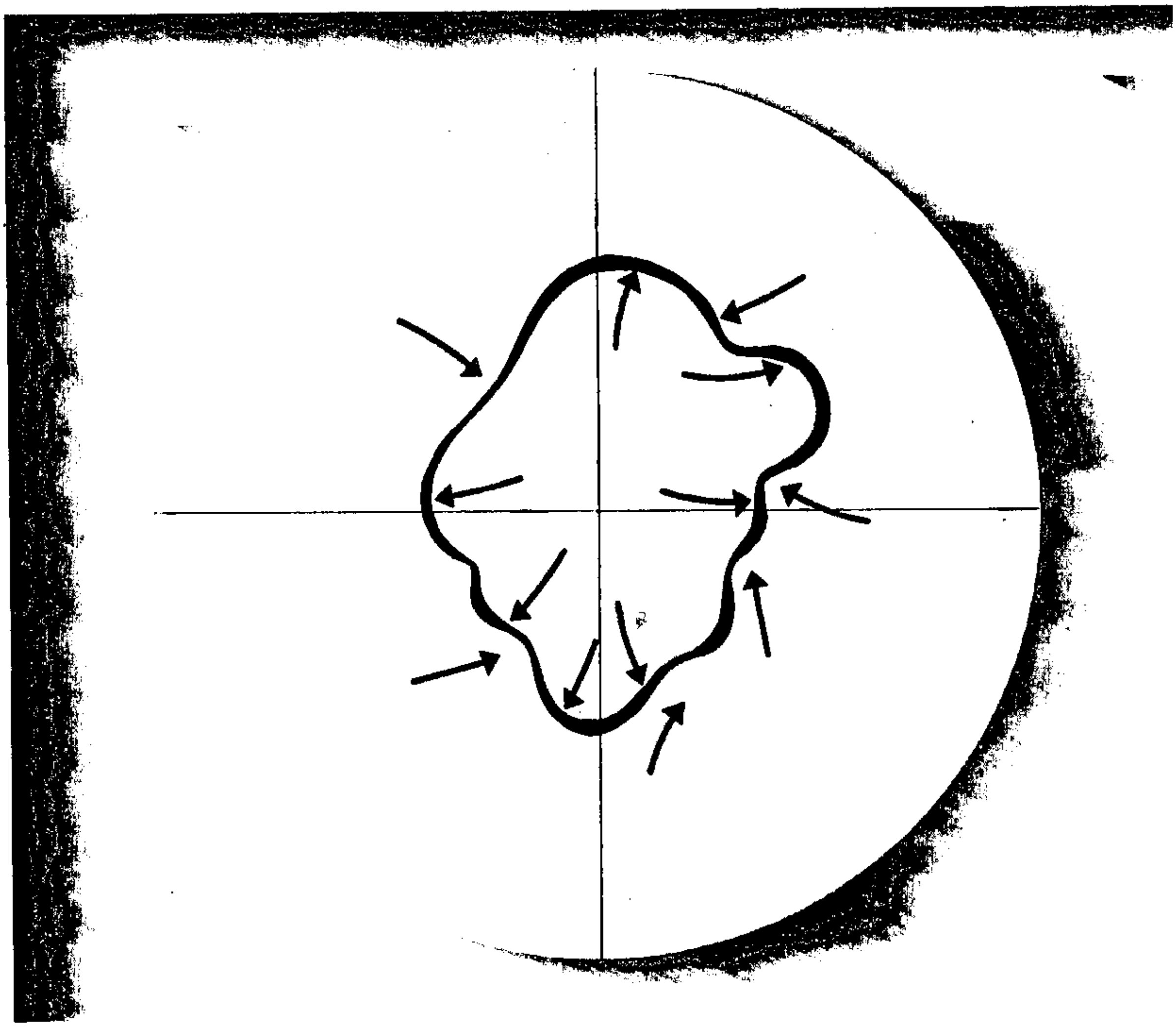


FIGURE 62. Hemispheric view of the polar front.

are dominant then. In summer, when warm air masses dominate, the front may move as far north as the 60th parallel.

The polar front is not the only front which may exist. It is the main zone of discontinuity in each hemisphere, but fronts may form between any air masses having sufficiently different temperature and moisture properties.

DISCONTINUITIES ACROSS FRONTS

Differences in the properties of adjacent air masses, such as temperature, moisture, and wind, are used by weathermen to locate and classify fronts. In addition, pressure changes are a very important indication of the position of a moving front. Cloud types are also useful indicators and will be discussed in connection with each individual type of front.

When a pilot passes through a front, or when a front moves past a weather observing station, the change experienced from the properties of one air mass to those of the other is sometimes quite abrupt. Abrupt changes indicate that the zone of transition is narrow, on some occasions less than a mile wide. At other times, the change of properties is very gradual due to a broad and diffuse transition zone, often over 200 miles in width.

TEMPERATURE

Temperature is one of the most easily recognized discontinuities across a front. At the earth's surface, the passage of a front is usually characterized by a noticeable change in temperature. The amount and rate of change is a partial indication of the front's intensity. Strong or sharp (narrow) fronts are accompanied by abrupt and sizeable temperature changes. Weak or diffuse fronts are characterized by gradual and minor changes in temperature.

When flying through a front, the pilot will note a more pronounced change in temperature if crossing it at a low altitude than if crossing it at a high altitude. The point to remember is that the temperature change, even when gradual, is faster and more pronounced than a change during a flight wholly within one air mass. Chapter 3 mentioned the effect of a temperature change on the aircraft altimeter, and it is especially important to obtain a new altimeter setting after crossing a front.

DEW POINT

The dew point temperature, together with the air temperature, gives a rough indication of the relative humidity of the air. Since the cold air mass usually will be drier than the warm, dew points reported from the weather observing stations are helpful in locating the position of the front. The dew point values by themselves can also indicate the position of the front since they ordinarily are lower in the cold air mass than in the warm.

WIND

Near the earth's surface, the discontinuity of wind across a front is primarily a matter of a change in direction. In the Northern Hemisphere, the wind changes direction in a clockwise rotation as a front passes. In flying across a front, regardless of the direction of flight, a simple rule pertaining to the wind shift is: To maintain your original ground track, you must change your heading to the right.

Wind speed often is very much the same on both sides of a front. In many cases, however, when flying from warm to cold air, one finds that the wind speed increases abruptly since in general wind speeds are greater in the cold air mass.

PRESSURE CHANGES

Since a front is usually found along a low pressure trough, the pressure normally is higher on both sides of the front than at the front. Thus, when a front is approaching a station, the pressure is usually decreasing. Since fronts usually have considerable clouds and precipitation with them, laymen have long associated falling pressure with the approach of bad weather. This rule must be used with caution, however, since the daily variation in pressure can cause a pressure fall even though the weather is very good and remains so.

In the usual situation, the pressure rises immediately following the frontal passage. But, not all fronts are found in major low pressure troughs. Sometimes the major trough becomes stationary and the front will tend to move out of it within a minor trough.

Troughs of low pressure also often develop within air masses; never in the history of these troughs have they had a front associated with them. Troughs denote areas where air is coming together from two directions (convergence) without any marked horizontal temperature difference in the area. The convergence favors lifting of the air, and troughs at middle and low latitudes are ideal locations for thunderstorm activity.

The pilot should not conclude that all weather of importance to flying occurs along fronts. In fact, very large areas of low ceilings and poor visibility often occur far removed from a front.

FACTORS INFLUENCING FRONTAL WEATHER

The weather along fronts is not always severe. Flying weather can vary from a condition of very little consequence to one which is extremely hazardous, including hail, severe turbulence, icing, low clouds, and poor visibility.

The clouds and precipitation occurring along a front are dependent on such factors as (1) the amount of moisture available, (2) the degree of stability of the air that is lifted, (3) the slope of the front, (4) the speed of the frontal movement, and (5) the amount of temperature and moisture contrast between the air masses.

With reference to the first factor, obviously sufficient moisture must be available for clouds to form—otherwise there will be no clouds.

The degree of stability of the air that is lifted determines whether cloudiness will be predominantly stratiform or cumuliform. With stratiform clouds, precipitation is usually steady, but there is little or no turbulence. Precipitation from cumuliform clouds is of a showery type, and the clouds are turbulent.

Shallow frontal surfaces tend to give extensive cloudiness with large precipitation areas. Fronts with steep slopes tend to move rapidly and to produce narrow bands of cloudiness and showery precipitation. Steep frontal slopes normally separate air masses of vastly different properties and, assuming that sufficient moisture is available and the warm air mass is conditionally unstable, they are especially intense when the cold air mass is moving rapidly toward the warm air. With these conditions, thunderstorms frequently accompany the front.

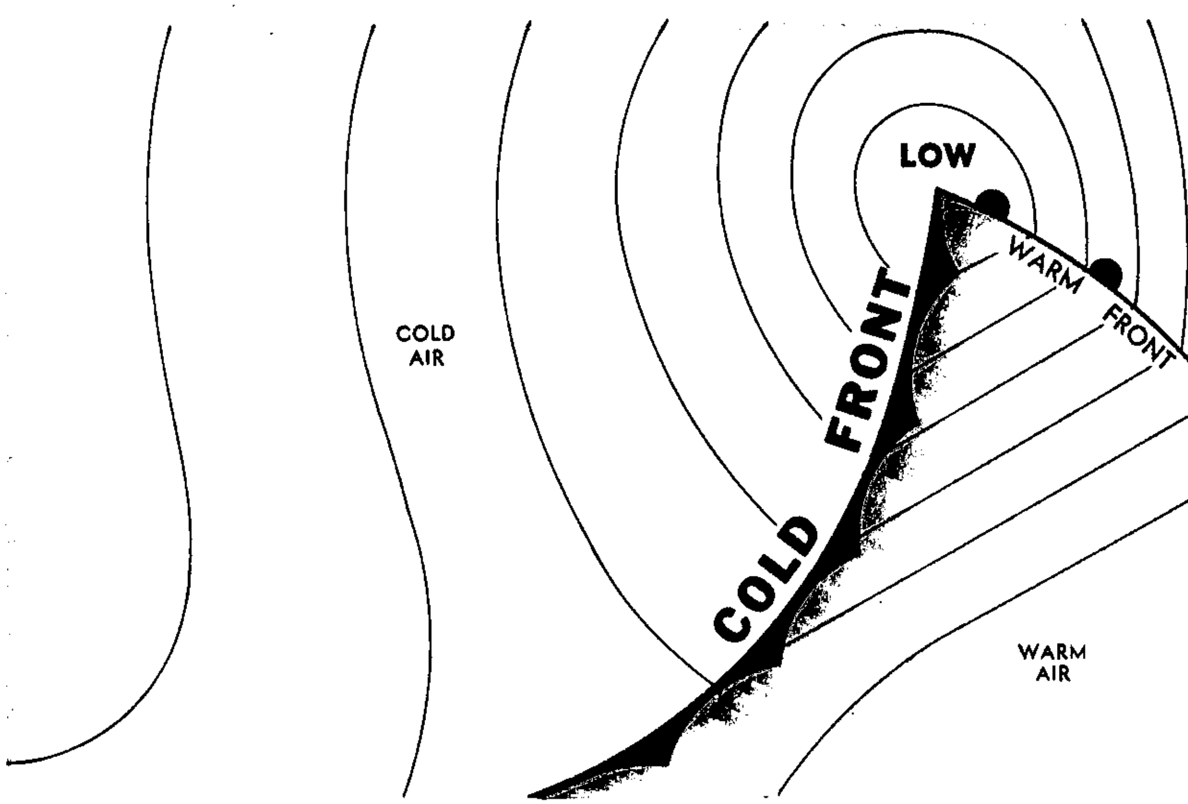


FIGURE 63. A cold front on a surface weather chart.

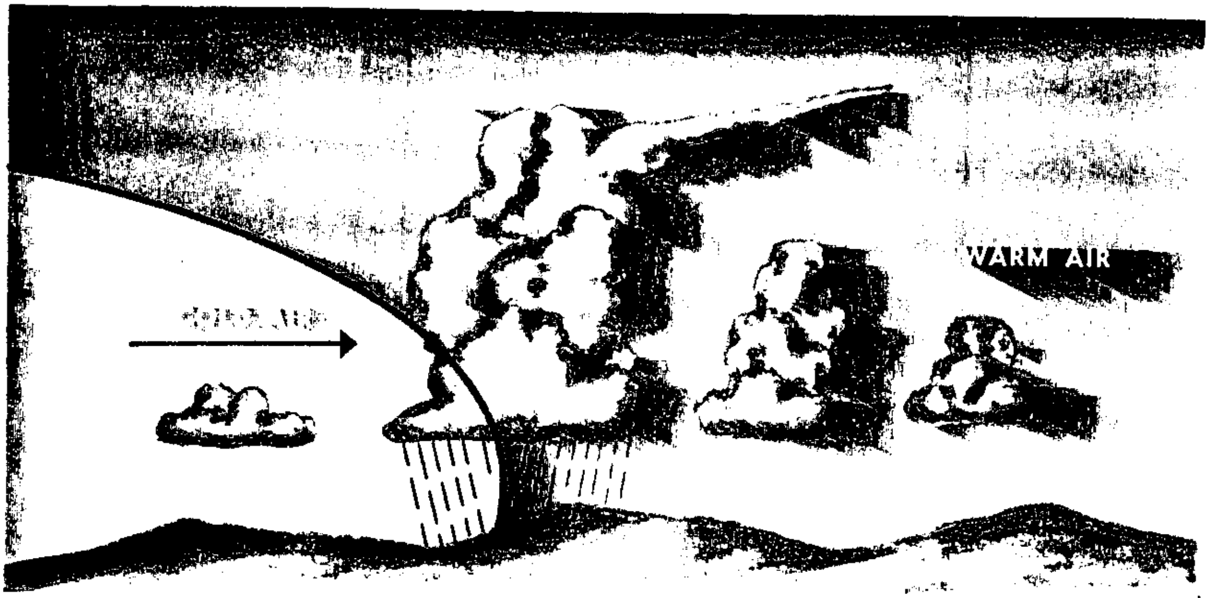


FIGURE 64. A cold front in vertical cross section.

COLD FRONTS

The leading edge of an advancing cold air mass is called a cold front—that is, the cold air is overtaking and replacing warmer air. Cold frontal slopes range from 1/50 to 1/150 and average about 1/80. A slope of 1/80 means that at 80 miles into the cold air from the surface position of the front, the front would be encountered 1 mile above the ground. Cold fronts are usually accompanied by very marked weather changes and some of the most hazardous flying weather. Figure 63 shows the manner in which a cold front is depicted on a surface weather chart. A "cross-sectional" view of the cold front is given in figure 64. At this

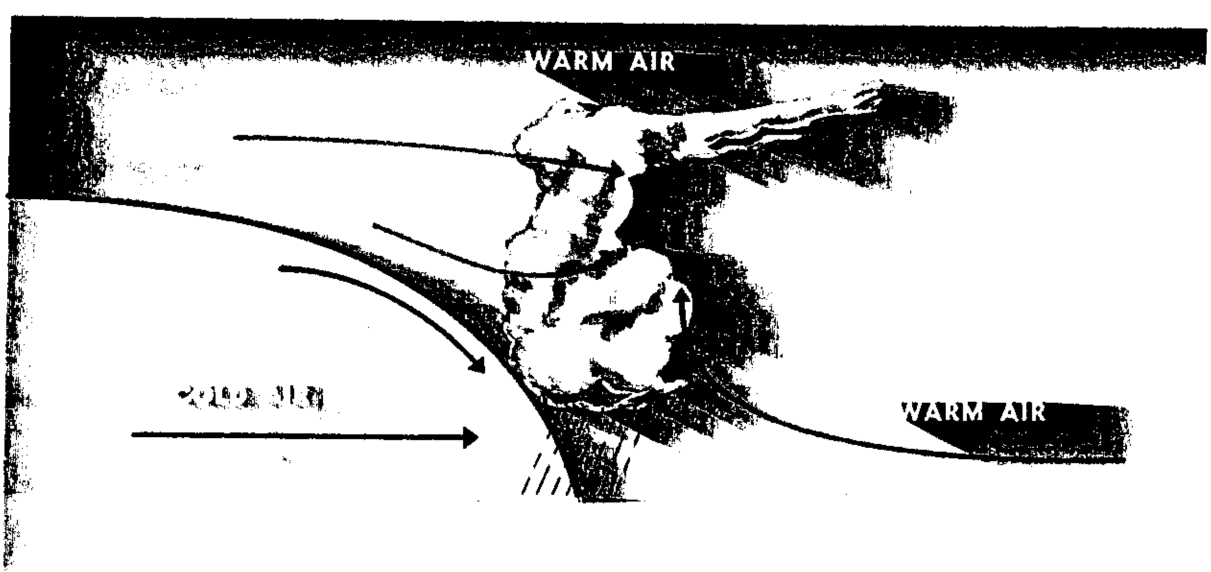


FIGURE 65. A fast-moving cold front, with unstable warm air.

point, it might be well to emphasize that the vertical dimensions of the fronts are exaggerated in all of the illustrations of frontal structure with height. This is done for increased clarity.

In the Northern Hemisphere, strong cold fronts are usually oriented in a northeast to southwest direction and move toward the east and southeast. They are followed by cooler and drier weather; they often precede severe cold spells in winter and sometimes dust storms. The sequence of events with the passage of a typical cold front is as follows: First, the southerly winds in the warm air lying ahead of the front increase. Then, altocumulus clouds appear on the horizon in the direction from which the front is approaching. The barometric pressure decreases. Next, the clouds lower and rain begins as the cumulonimbus clouds move in. The rain increases in intensity when the front nears the station. As the front passes, the wind shifts to a westerly or northerly direction, and the pressure rises sharply. This type of cold

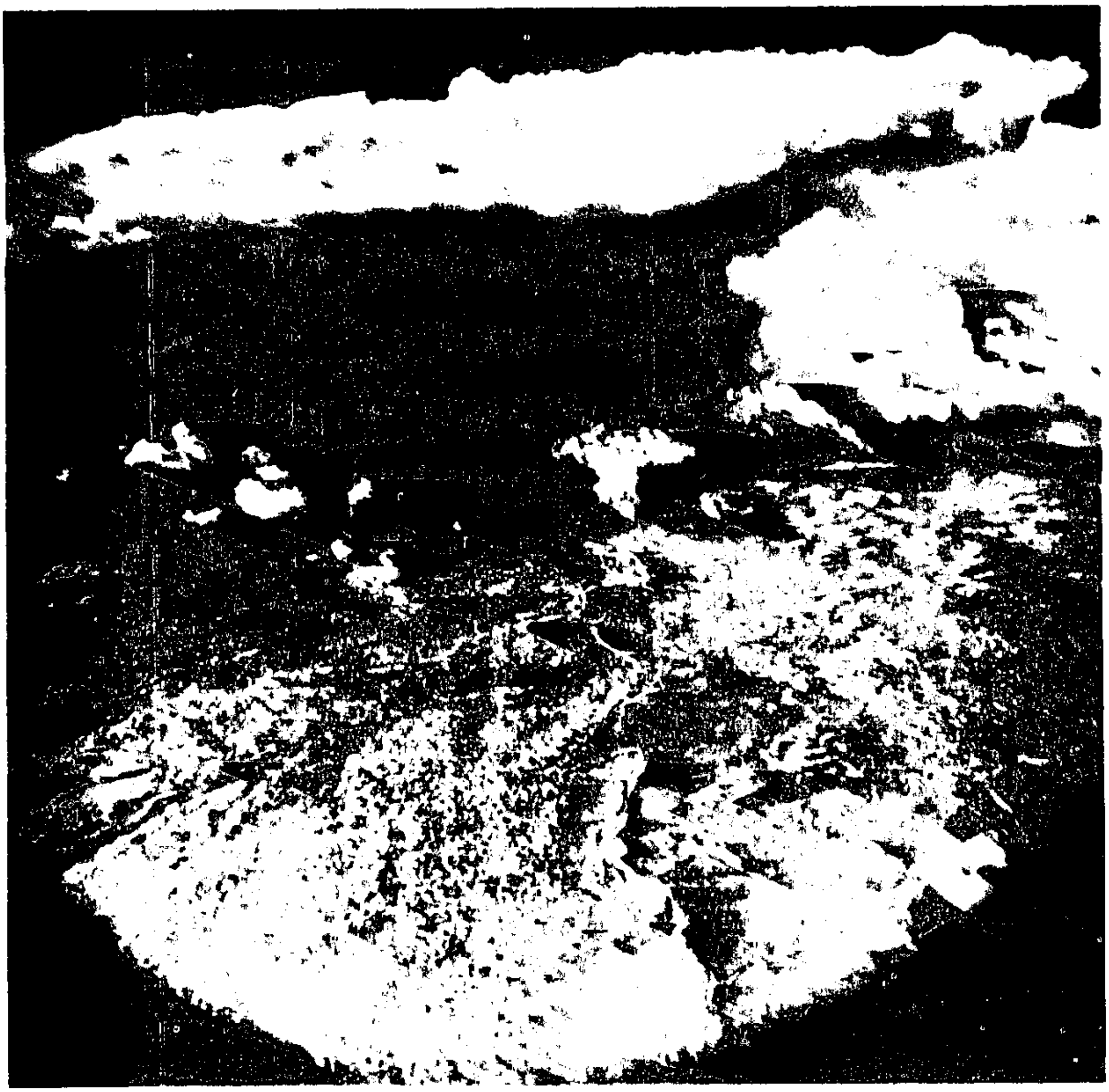


FIGURE 66. An aerial view of a portion of a squall line.

front passage normally is followed by rapid clearing with falling temperature and dew point. The cloudiness in the cold air depends on the degree of stability and moisture content of the air mass. The sequence of events described here may, in many cases, be considerably altered.

Cold fronts may be divided into two general types: fast-moving and slow-moving. These types often change gradually from one to the other. In extreme cases, cold fronts have been observed to move with speeds of 60 or more miles per hour, but they normally move at less than half this speed. They usually move faster in winter than in summer.

FAST-MOVING COLD FRONTS

With a cold front that is moving rapidly, there is downward movement of air both above and below the frontal surface aloft. In the area ahead of the surface position of the front, the air is moving upward (see fig. 65). As would be expected, most of the heavy cloudiness and precipitation is located just ahead of the front where the opposing air currents meet. This type of front often causes very hazardous flying weather.

As mentioned earlier, friction often retards the front near the surface. This causes its slope to steepen, and a narrower band of weather results. If the warm air mass is moist and conditionally unstable, scattered thunderstorms and showers are likely to develop ahead of the front. In some cases, a continuous line of thunderstorms develops. This line, known as a "squall line," is often characterized by a formidable wall of turbulent clouds building to 40,000 feet or higher (see fig. 66). In some cases, individual clouds extending to 60,000 or 70,000 feet have been observed. The squall line sometimes develops between 50 and 300 miles ahead of the front and is roughly parallel to it. Squall lines are accompanied by some of the most turbulent weather known. The weather usually clears rapidly behind a fast-moving cold front, with colder temperatures and gusty, turbulent surface winds following its passage.

SLOW-MOVING COLD FRONTS

When the cold front is moving slowly, there is a general upgliding of the warm air over the frontal surface. This results in a rather broad cloud pattern in the warm air, with the clouds extending well behind the surface position of the front. If the warm air is stable, the clouds are stratiform (see fig. 67); cumuliform clouds and, frequently, thunderstorms develop if the warm air is moist and conditionally unstable (see fig. 68).

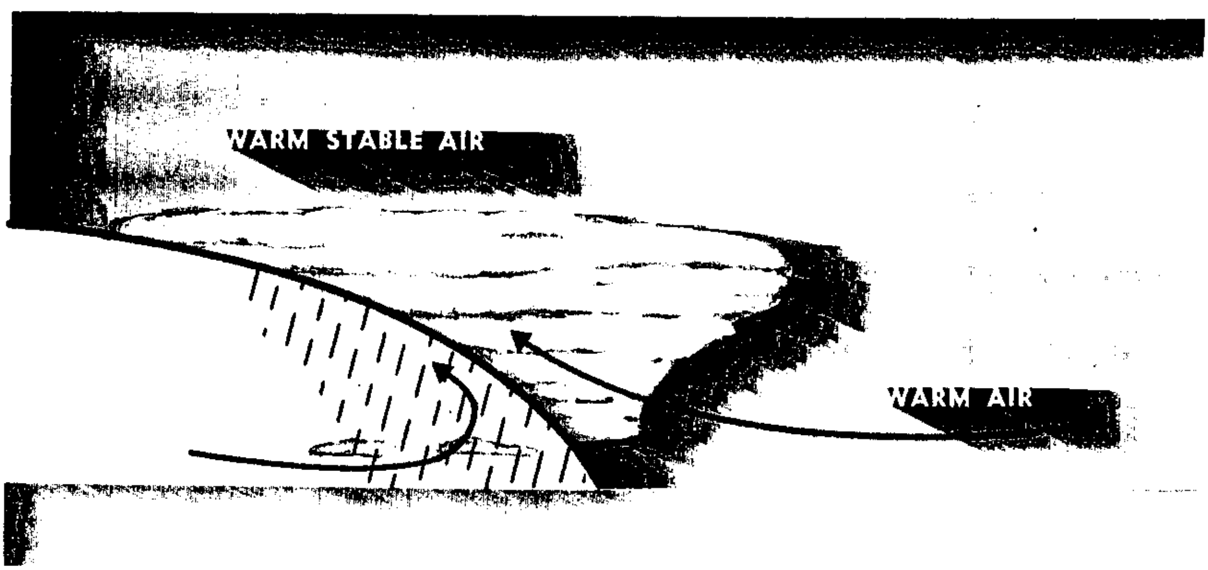


FIGURE 67. A slow-moving cold front, with stable warm air.

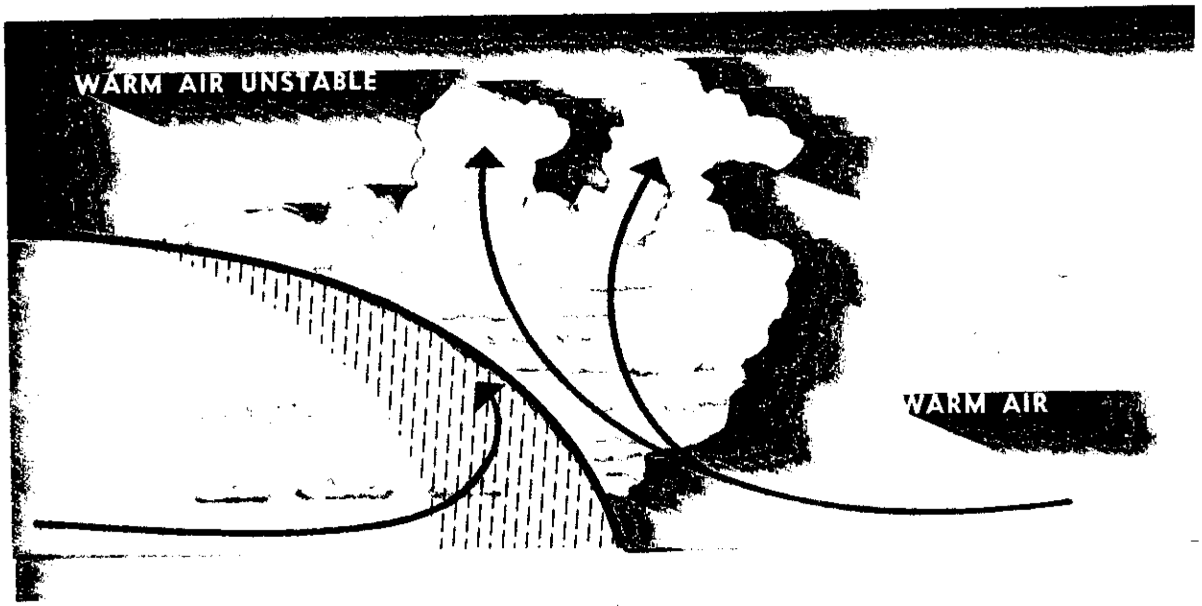


FIGURE 68. A slow-moving cold front, with unstable warm air.

WARM FRONTS

The leading edge of an advancing warm air mass is called a warm front—that is, warm air is overtaking and replacing colder air. Warm frontal slopes range between 1/50 and 1/200, with an average of 1/100. Warm fronts are seldom as well marked as cold fronts, and they usually move about half as fast when the general wind flow is the same in each case.

The warm air gradually moves up over the frontal surface, and a broad cloud system

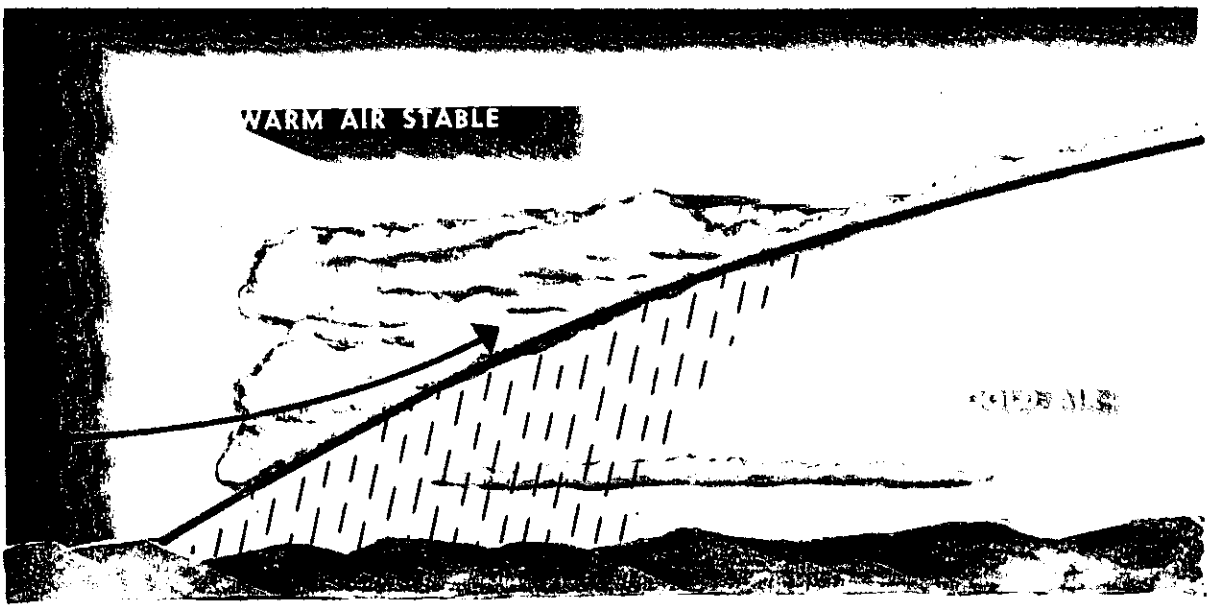


FIGURE 69. A warm front, with stable warm air.

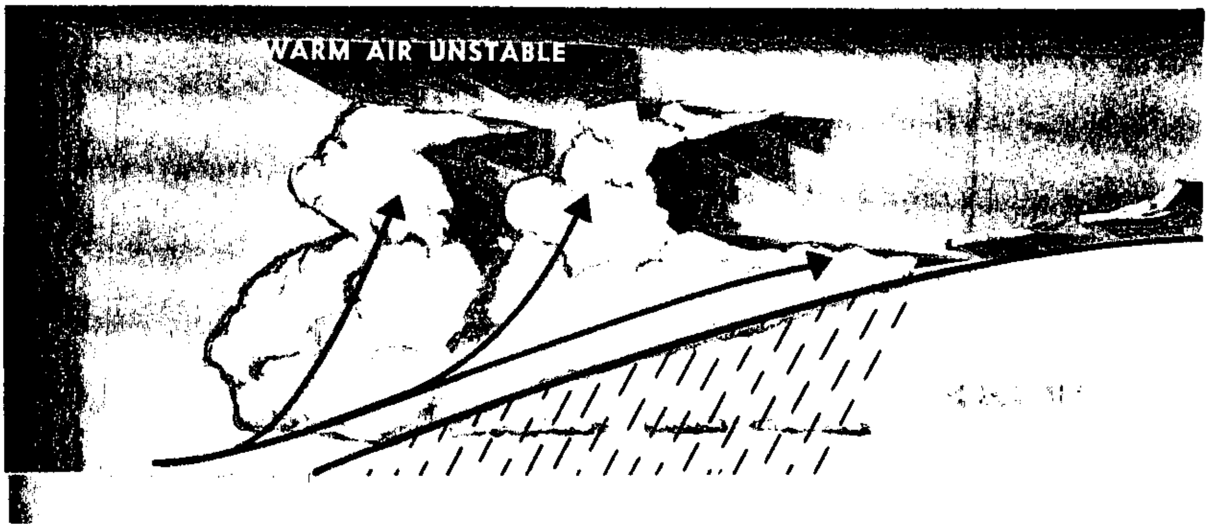


FIGURE 70. A warm front, with unstable warm air.

usually forms. This cloud system extends from the surface position of the front to about 500 to 700 miles in advance of it.

If the warm air is moist and stable, stratiform clouds develop. The sequence of cloud types encountered when flying in a direction opposite to the movement of the front is cirrus, cirrostratus, altostratus, and nimbostratus (see fig. 69). Precipitation increases gradually with the approach of this type of warm front and usually continues until it passes.

If the warm air is moist and conditionally unstable, altocumulus and cumulonimbus clouds, and frequently thunderstorms, will be embedded in the cloud masses which normally accompany any warm front (see fig. 70). The presence of these thunderstorms is often unknown to the pilot until he enters them. Precipitation in advance of the front is usually showery with this condition.

The widespread precipitation area ahead of a warm front often causes low stratus and fog

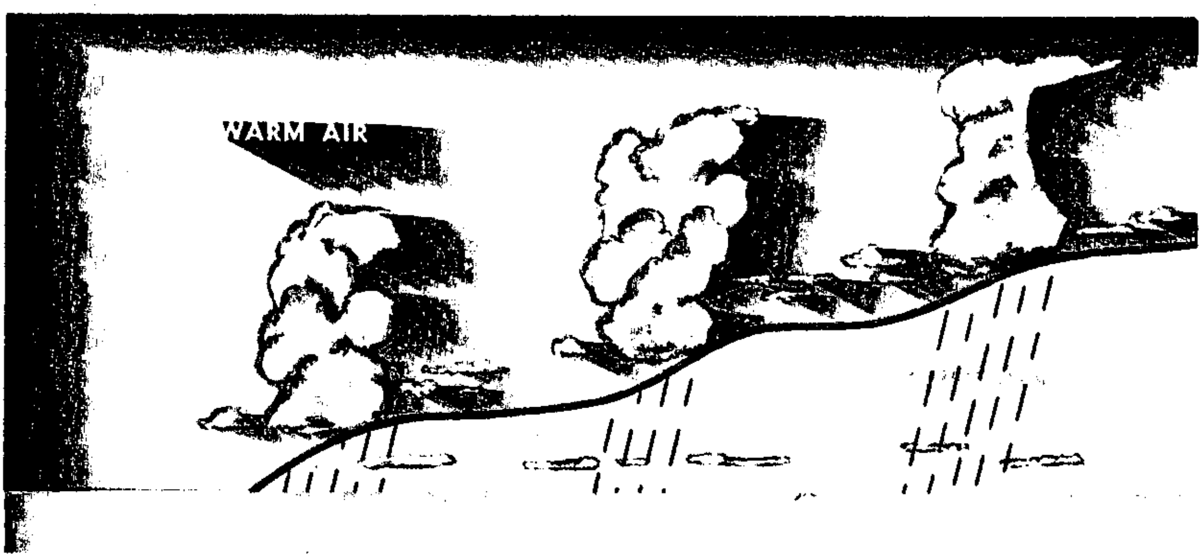


FIGURE 71. A wavy warm frontal surface.

to form. In this case, the rain raises the humidity of the cold air to saturation. This and related effects may produce low ceilings and poor visibility over thousands of square miles. The frontal zone itself may have zero ceilings and visibilities over a wide are^. If the cold air has below-freezing temperatures, the precipitation may take the form of freezing rain or sleet.

Very cold air underneath a warm front resists displacement and may force the warm air to move over a thinning wedge with waves in the upper surface. This gives the effect of secondary upper warm fronts and may cause parallel bands of precipitation at unusual distances ahead of the surface warm frontal position (illustrated in fig. 71).

STATIONARY FRONTS

Sometimes the opposing forces exerted by adjacent air masses of different densities are such that the frontal surface between them shows little or no movement. In such cases, it is usually found that the surface winds tend to blow parallel to the front rather than against and/or away from it. Since neither air mass is replacing the other, the front is called a stationary front (see the surface weather chart in fig. 72).

The weather conditions occurring with a stationary front are similar to those found with a warm front but are usually less intense. An annoying feature of the stationary front and its weather pattern is that it may persist and hamper flights in one area for several days.

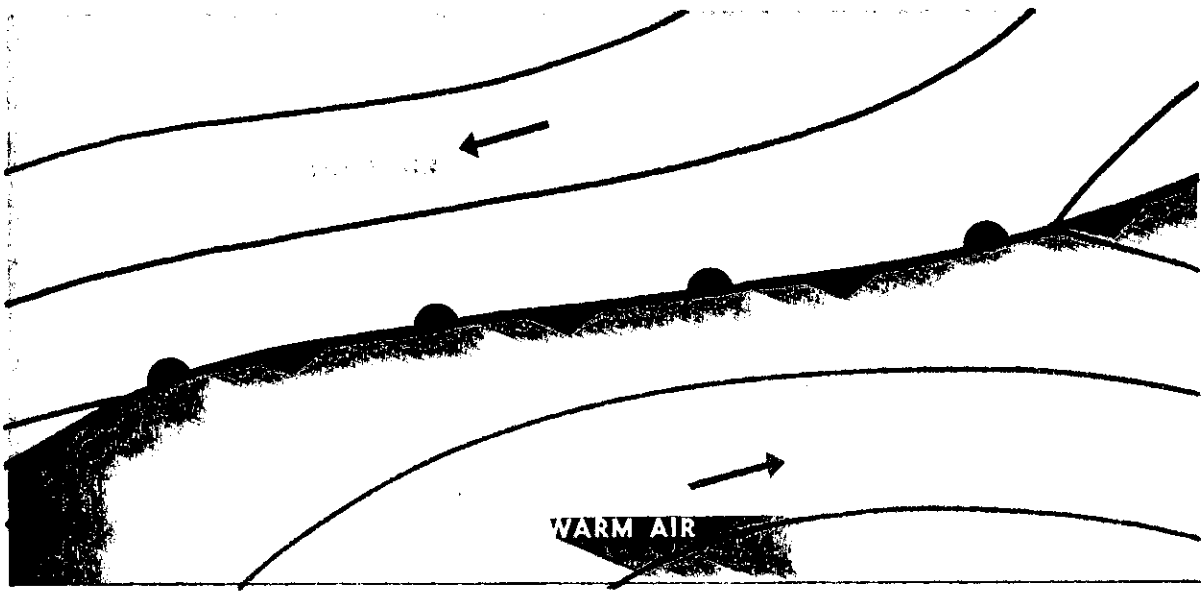


FIGURE 72. A stationary front on a surface weather chart.

FRONTAL WAVES AND OCCLUSIONS

Frontal waves and cyclones (areas of low pressure) are primarily the result of the interaction of two air masses; they usually form on slow-moving cold fronts or stationary fronts.

In the initial condition in figure 73, the winds on both sides of the front are blowing parallel to it (A). Small disturbances in this pattern of winds, as well as perhaps uneven local heating and irregular terrain, may start a wavelike bend in the front (B). These disturbances

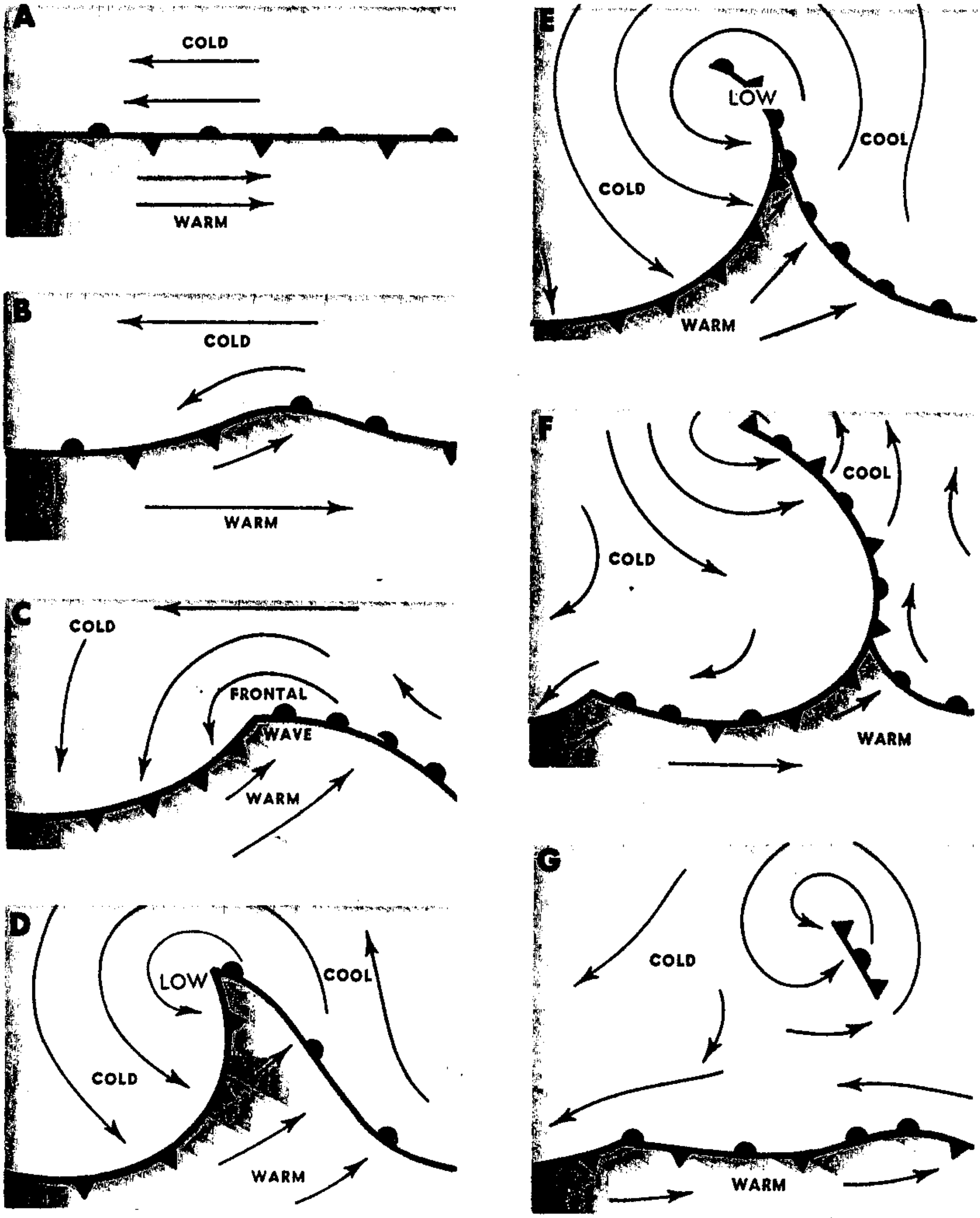


FIGURE 73. The life cycle of a frontal wave.

often are not obvious on the weather chart. If this tendency persists and the wave increases in size, a counterclockwise (cyclonic) circulation is set up. One section of the front begins to move as a warm front, while the section next to it begins to move as a cold front (C). This deformation is called a frontal wave.

The pressure at the peak of the frontal wave falls, and a low-pressure center is formed. The cyclonic circulation becomes stronger, and the surface winds are now strong enough to move the fronts; the cold front moves faster than the warm front (D). When the cold front catches up with the warm front, the two of them occlude (close together). The result is called an occluded front or, for brevity, an occlusion (E). This is the time of maximum intensity for the wave cyclone. Note the manner in which the occluded front is designated on this surface weather chart.

As the occlusion continues to grow in length, the cyclonic circulation diminishes in intensity (the low pressure area weakens) and the frontal movement slows down (F). Sometimes a new frontal wave may now begin to form on the long westward-trailing portion of the cold front. In the final stage, the two fronts have become a single stationary front again. The low center with its remnant of the occlusion is disappearing (G).

Figure 73 shows how one section of a frontal wave moves toward the cold air as a warm front, while an adjacent section moves toward the warm air as a cold front. Figure 74 consists of two vertical cross-sections of the frontal wave, one to the north of the surface position of the wave, and the other across the cold and warm fronts of the wave. The cold front section usually moves faster than the warm front section and eventually overtakes it to form the occlusion. The warm air mass (warm sector), which was between the fronts, is lifted up off the surface by the two colder air masses. The resulting occluded front may be one of two types—the cold front occlusion or the warm front occlusion.

COLD FRONT OCCLUSION

In the cold-front occlusion, the air ahead of the warm front is "less cold" than the air behind the overtaking cold front. When the cold front overtakes the warm front, both the warm air behind the warm front and the cold air ahead of it are lifted by the colder air coming in behind the cold front. Thus, the warm front itself is lifted by the undercutting cold front, and it becomes an *upper warm front.* At the surface, the situation resembles that found with the cold front (in this case, cold air is displacing cool air)—hence the name *cold front occlusion.*

Figure 75 illustrates the structure of the occluded wave as it might be designated on a surface weather chart. However, in practice the upper warm front position is seldom indicated on the weather chart. A cross-sectional view of the cold front occlusion portion of figure 75 is shown in figure 76.

In the occlusion's initial stage of development, the weather and cloud sequence ahead of the occlusion are similar to that associated with warm fronts, while the clouds and weather near the surface position of the front are similar to that associated with cold fronts. As the occlusion develops and warm air is lifted to higher and higher altitudes, the warm front prefrontal cloud system disappears; the weather and cloud system become similar to those of a cold front. Cold front occlusions form predominantly over continents or along their east coasts and are more common than warm-front-type occlusions.

WARM FRONT OCCLUSION

In the warm-front occlusion, the air ahead of the warm front is colder than the air behind the overtaking cold front. When the cold front overtakes the warm front, both the warm air ahead of the cold front and the cool air behind it slide up over the colder air which is ahead of the warm front. Thus, the cold front itself moves up over the warm front, pushing the warm air ahead of it, and becomes an *upper cold front.* At the surface, the situation resembles that found with a warm front (in this case, cool air is replacing cold air)—hence the name *warm front occlusion.* This type of occlusion is not common over the interior of the United States. Figure 77 illustrates the structure of the occluded wave as it might be designated on a surface weather chart. Sometimes

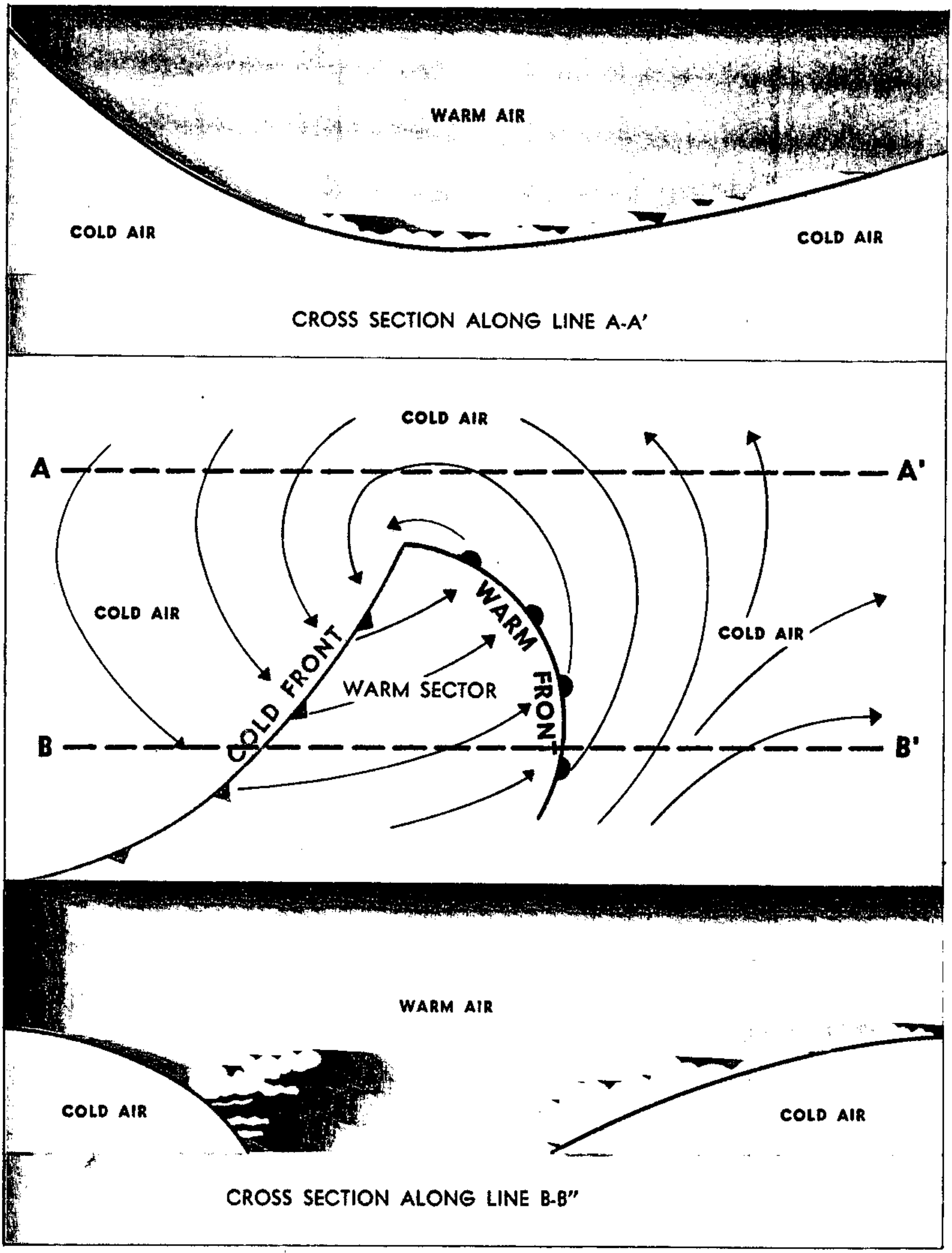


FIGURE 74. A frontal wave on a surface weather chart, with cross sections along two lines.

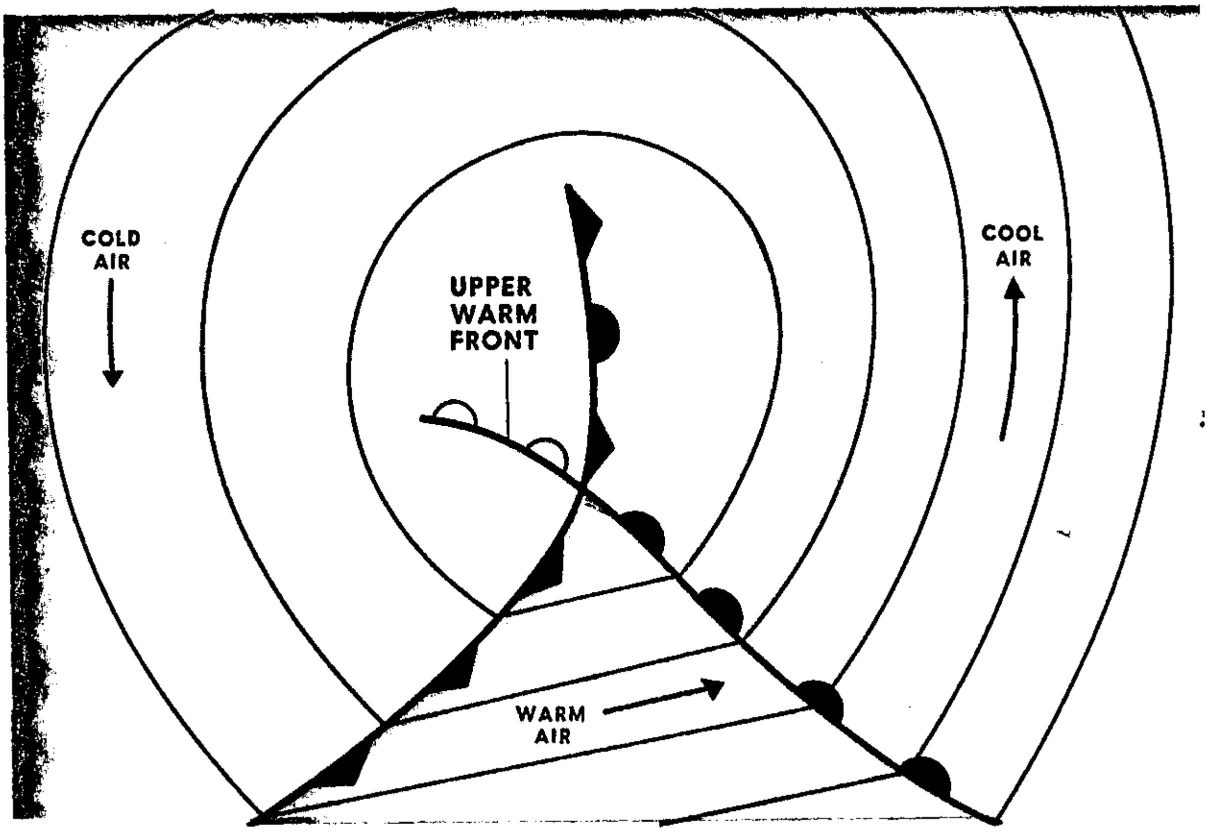


FIGURE 75. The structure of an occluded frontal wave on a surface weather chart.

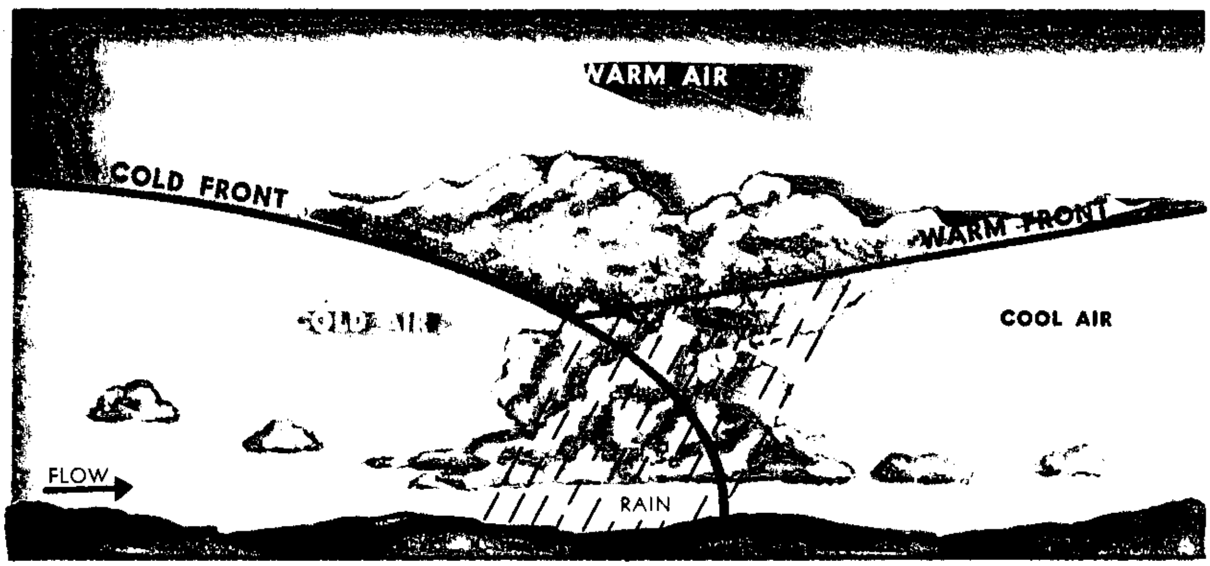


FIGURE 76. A cold-front occlusion in vertical cross section.

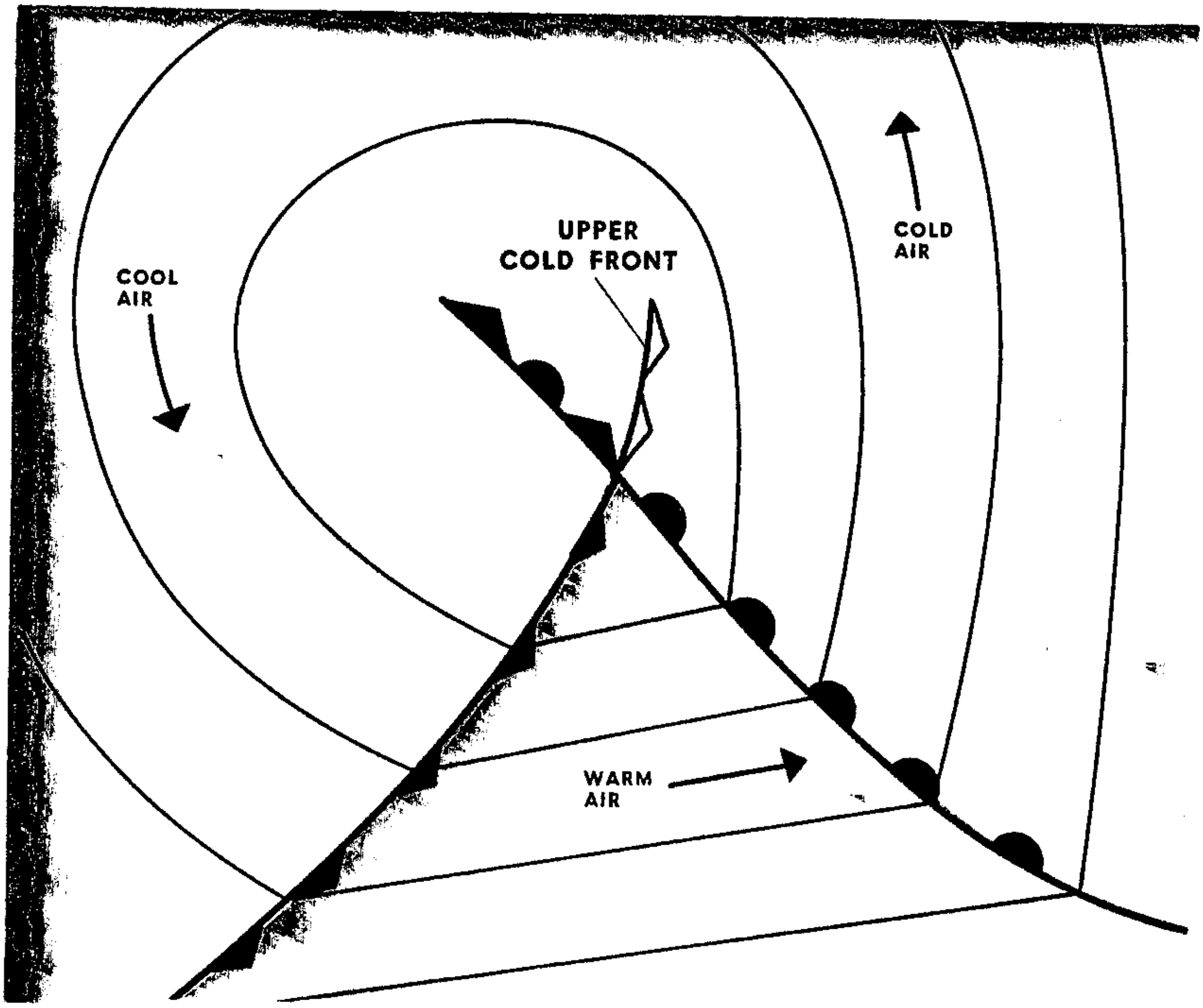


FIGURE 77. The structure of a warm-frontal occlusion on the surface weather chart.

the upper cold front position is indicated on the surface weather chart when its position is clearly delineated by a significant fall in sea level pressure.

The weather associated with warm front occlusions has the characteristics of both warm and cold fronts, as figure 78 shows. The sequence of clouds ahead of the occlusion is similar to the clouds ahead of a warm front, while the cold front weather occurs near the upper cold front. If either the warm or cool air which is lifted is moist and unstable, showers (and sometimes thunderstorms) may develop. Weather conditions change rapidly in occlusions, and are usually most severe during the initial stages of development. However, as the warm air is lifted to higher and higher altitudes, the weather activity diminishes. Warm front occlusions are found predominantly along the west coasts of continents.

UPPER FRONTS

In addition to the upper warm front associated with a cold occlusion, and the upper cold front accompanying the warm occlusion, there is one other significant type of upper front, which occurs primarily in winter. This is a cold front aloft which moves over an even

FIGURE 78. A warm-front occlusion in vertical cross section.

colder air mass lying in the lower layers of the atmosphere near the surface. Figure 79 illustrates such a front east of the Rockies. Note that the frontal activity takes place above the top of the very cold continental polar air. Since cP air masses seldom move west of the Rockies, upper fronts of this type are most commonly found over the eastern portion of North America.

INACTIVE FRONTS

Often a pilot will find a front designated on a surface weather chart in an area where he has just flown and found no weather of importance. As mentioned earlier, fronts are not always accompanied by clouds and precipitation. Sometimes the warm air mass is too dry for clouds to form even after the cooling which results from its being lifted up the frontal slope.

The primary purpose of continuing to show the "dry front" on the weather chart is to indicate the boundary of the opposing air masses, since it is a location of potentially unfavorable flying weather. The warm air mass may be gradually becoming more moist; in this case, clouds and precipitation would be expected in the frontal zone at a later time. Also the dry front usually is associated with a change in wind conditions at the surface and at least in the lower levels aloft.

FRONTOLYSIS

The manual has covered the nature of fronts, how they move, and how they change from one type to another. One might wonder what becomes of fronts. Obviously they can't last forever. The air masses get farther and farther away from "home," the cold air masses move into the domain of tropical air and vice versa. Since the replacing air mass is constantly being modified in its travel, it eventually becomes little different from the air mass it is replacing.

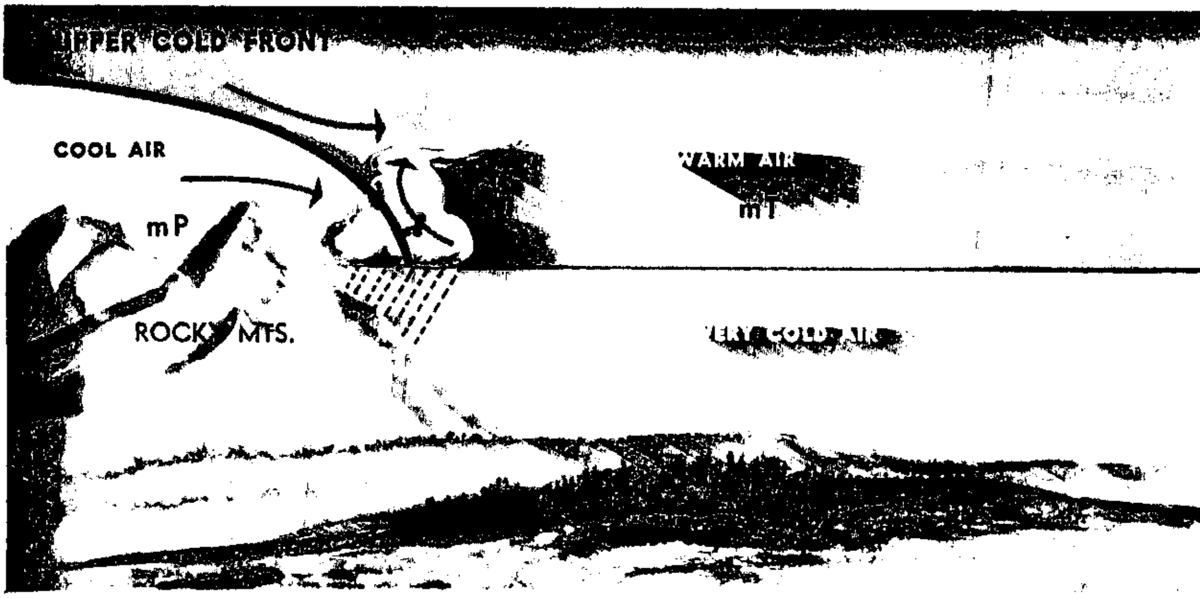


FIGURE 79. An upper cold front.

As the air masses become more and more alike, the fronts, like "old soldiers," gradually fade away.

An example of frontolysis is shown in figure 80. Note that as the zone of transition between the air masses becomes more and more diffuse, the weatherman designates this by putting breaks in the line designating the stationary front (B), and by alternating plain line segments with frontal line segments. In (C), he indicates that the front has broken down completely.

FRONTOGENESIS

The term "frontogenesis" means the generation of a front. It refers to situations where a relatively sharp zone of transition develops (a front forms) over an area between two air masses which have densities gradually becoming more and more in contrast with each other.

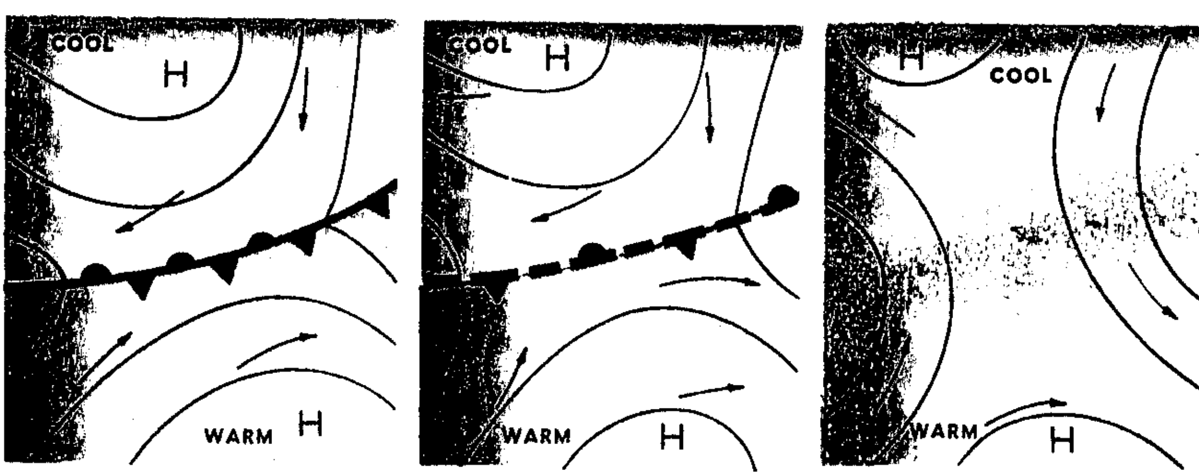


FIGURE 80. Frontolysis.

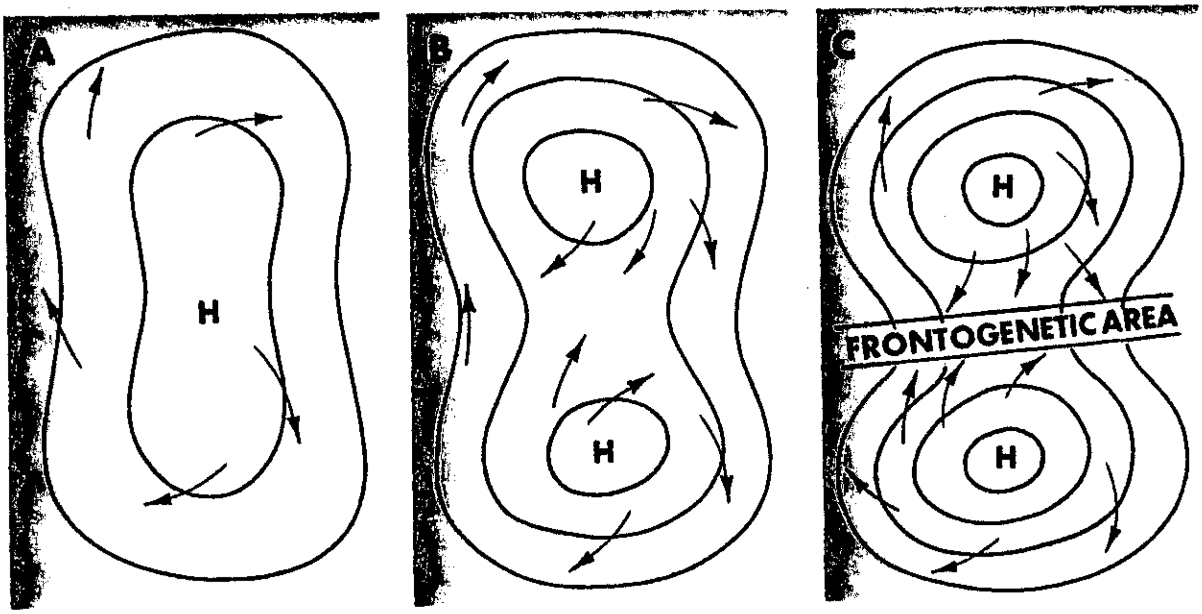


FIGURE 81. Frontogenesis.

The necessary wind flow pattern usually develops at the same time.

A common example of frontogenesis is shown in figure 81. The forming frontal boundary is designated on the surface weather chart as a broken line with the line symbols signifying the type of front (cold, warm, or stationary) which will evolve. The large high pressure system shown in the illustration has been stagnant for perhaps several days. Because of the large range of latitude covered, the air to the north remains colder than the air to the south. However, the change from one area to the other is initially very gradual. If the wind flow is weak, the two masses of air grow to be more unlike because the underlying surfaces modifying them have considerably different properties. If, at this time, the pressure is rising at the two ends, the resulting flow (B) carries some of the cool air southward and some of the warm air northward. Provided this condition persists long enough, the temperature change near the middle of the air mass can no longer be considered a gradual one. This area (C) is frontogenetic; it is only a matter of time until the contrast becomes so marked that we can distinguish two air masses where formerly there was only one. The front, in this example, is stationary.

Discontinuity in moisture content, produced in a similar manner to the temperature contrast, is also an important factor in front formation.

Chapter 11
THUNDERSTORMS

The thunderstorm is a local storm which invariably is produced by a cumulonimbus cloud and is always accompanied by lightning and thunder. The thunderstorm represents atmospheric convection at its strongest. It could be defined as the ultimate manifestation of the growth of a cumulus cloud.

Thunderstorms are particularly dangerous for pilots because many of the most severe atmospheric hazards are found within them. They are almost always accompanied by strong gusts of wind and severe turbulence. Heavy rain showers usually occur, and hail is not uncommon.

Obviously, thunderstorms should be avoided if possible. When forced to fly through them, even heavy aircraft must adhere to established safety precautions and procedures. But with about 44,000 thunderstorms occurring daily over the world, almost every pilot can expect to encounter one occasionally. A knowledge of thunderstorm characteristics and the application of tested procedures should assist the pilot in successfully flying through them if no alternate course of action exists.

Thunderstorms are daily occurrences in many parts of the Tropics throughout the year. In the middle latitudes, they occur most frequently

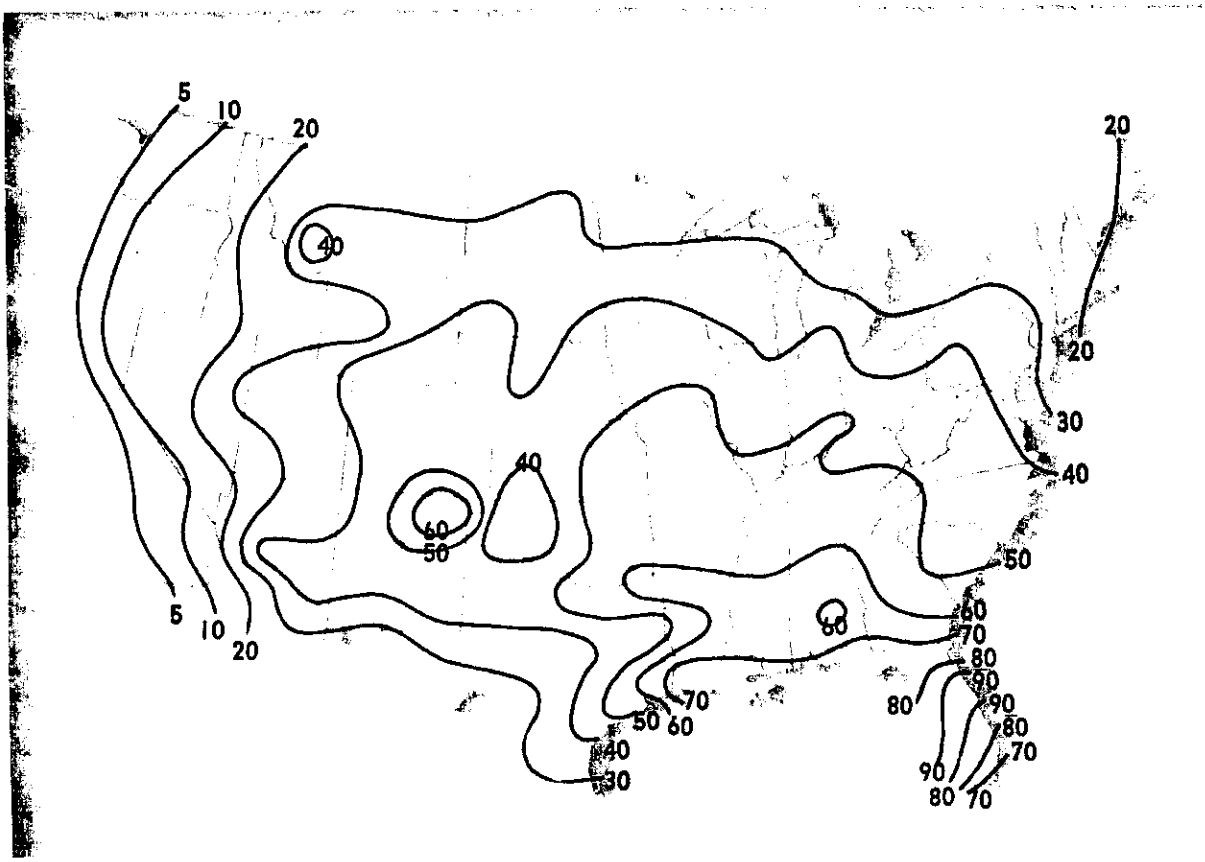


FIGURE 82. The average number of thunderstorms each year.

from late winter through the early fall; they sometimes accompany very active cold fronts even in midwinter. In summer, thunderstorms have occurred as far north as the Arctic region. They supply a large portion of the earth's rainfall, and in some areas such as Arizona, they are usually the only source of critically needed rainfall.

Figure 82 shows the average number of thunderstorms each year in various sections of the adjoining 48 States. Note that they rarely occur on the Pacific coast and are most frequent in the south-central and southeastern States. The number of "thunderstorm days" in a particular area varies from season to season as shown in figures 83 through 86. These charts do not indicate the frequency of occurrence of individual thunderstorms, but rather show the thunderstorm days regardless of the number of storms occurring on that day. In general, thunderstorms are encountered most frequently in July and August, and least frequently in December and January.

FACTORS NECESSARY FOR THUNDERSTORM FORMATION

The basic requirements for formation of a thunderstorm cloud are the same as for any other cloud of the convective type: (1) unstable air, (2) some type of lifting action, and (3) high moisture content of the air. Since the basic requirements are the same, one may ask why only fair weather cumulus clouds are present on one sultry, summer afternoon, and thunder-

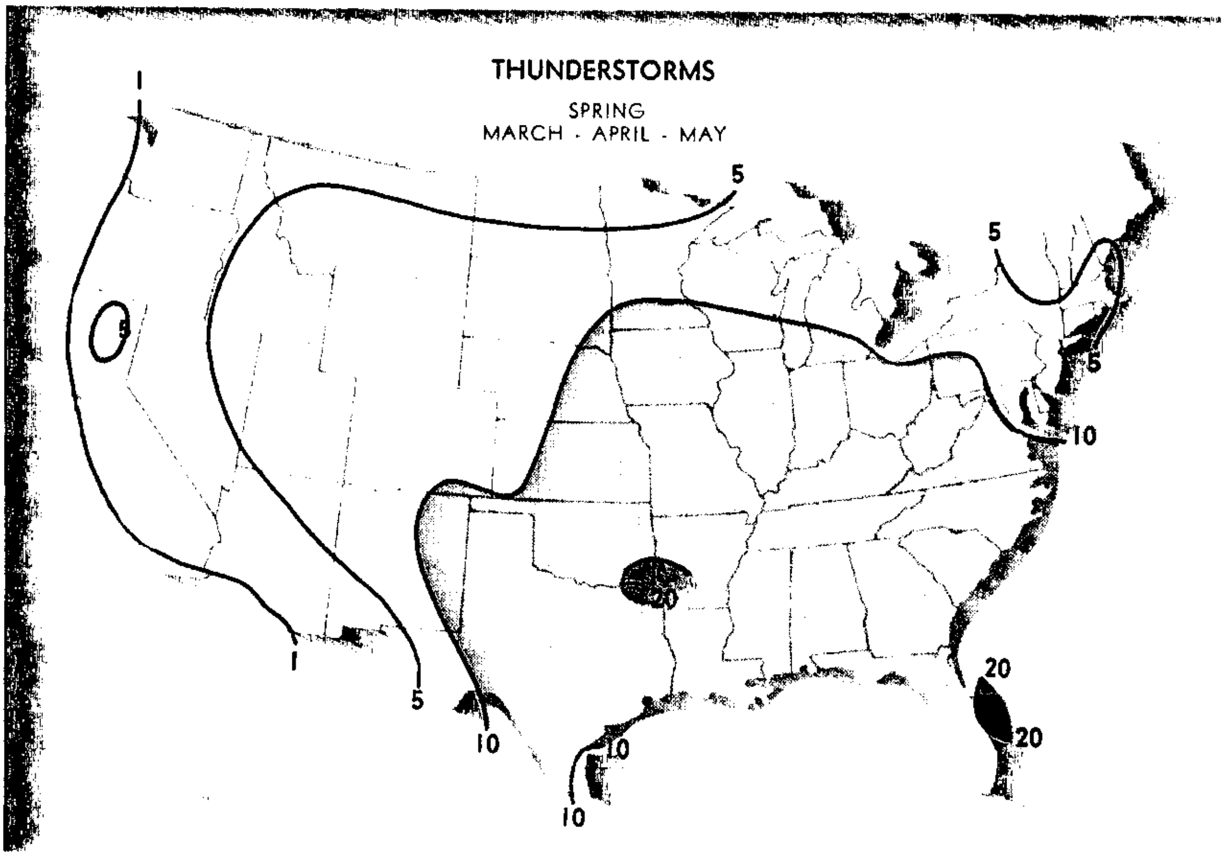


FIGURE 83. The average number of days during spring with thunderstorms.

storms are in abundance the next. The difference lies in the degree in which the causal factors are present.

UNSTABLE AIR

For thunderstorm formation, the air must be, at a minimum, conditionally unstable (see ch. 6). Conditionally unstable air, to become actually unstable, must be lifted to a point where it becomes warmer than its surroundings. This point is called the "level of free convection." When this level has been reached, the warmer air continues to rise freely until, at some altitude, it has cooled to the temperature of the surrounding air.

LIFTING ACTION

Some type of external lifting action is necessary to bring the warm air from near the surface to the level of free convection, above which it will rise freely. The lifting action may be furnished by (1) any type of front, (2) mountainous terrain, (3) heating from below, or (4) the vertical motions resulting from air coming together from two directions (convergence).

MOISTURE

Lifting of warm air will not necessarily cause free convection. The air may be lifted to the point where its moisture condenses and forms clouds, but these clouds will not grow significantly unless the air is lifted sufficiently to reach the level of free convection. The higher the moisture content, the easier the level of free convection is reached.

If the air contains very little moisture, it is likely that no clouds at all will form even though other factors present may be favorable for thunderstorms. This is a situation where turbulence is experienced in perfectly clear weather.

When sufficient moisture for condensation is

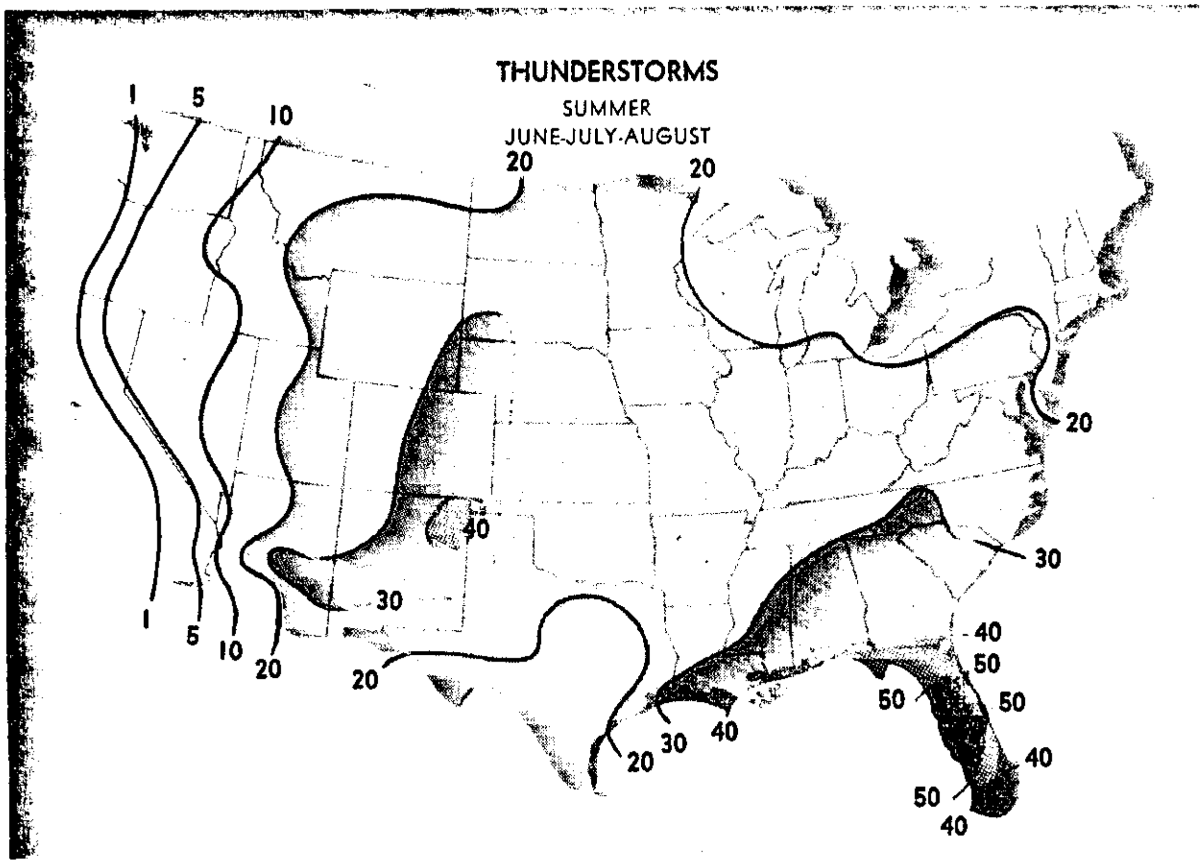


FIGURE 84. The average number of days during summer with thunderstorms.

available, the heat released in the condensation process tends to make the air more unstable. It is for this reason that, when other factors favor thunderstorm formation, the air need be only conditionally unstable rather than absolutely unstable.

Building upward of cumulus clouds into cumulonimbus and thunderstorms may be prevented by layers of air at intermediate altitudes (roughly between 6,000 and 15,000 feet) which are initially very stable and/or very dry. Under these conditions thunderstorms are unlikely even though all other factors favor their development.

THUNDERSTORM STRUCTURE

RELATIONSHIP OF DRAFTS AND GUSTS

Drafts are a prominent feature of all thunderstorms. Before discussing drafts in their connection to the thunderstorm's life, it is necessary to establish a clear understanding of the nature of drafts and how they compare to the smaller-scale irregularities in air movement known as gusts.

Drafts are large vertical currents of air which are continuous over many thousands of feet of altitude and over horizontal regions as large as an entire thunderstorm. An individual thunderstorm varies in diameter generally from 5 to 10 miles. While draft speeds generally vary gradually from one altitude to another, they are relatively constant in contrast to gusts which have speed variations over a wide range. Extending over short vertical and horizontal distances, gusts are small-scale, sudden, and brief increases in the speed of air movement. Gusts are primarily responsible for the severe

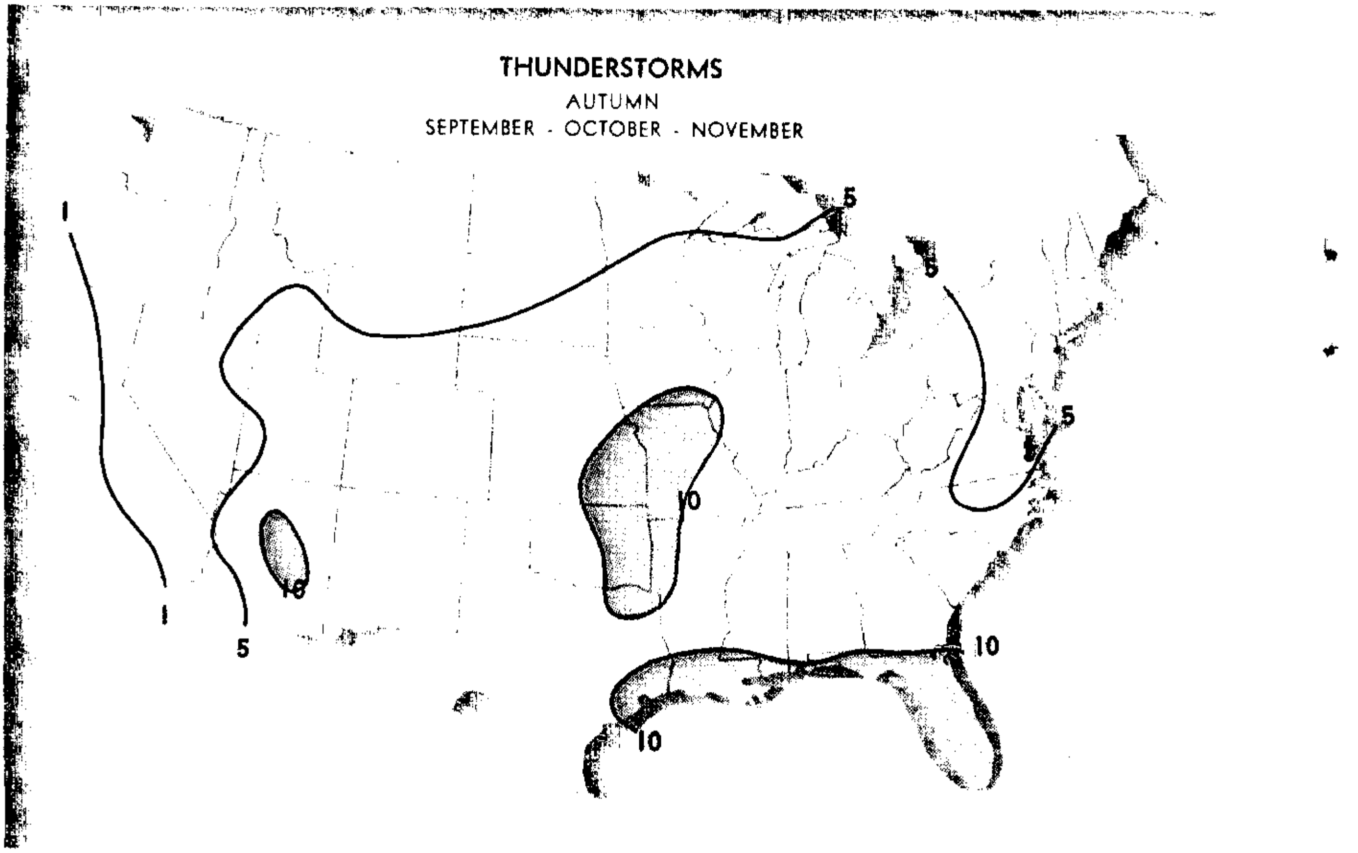


FIGURE 85. The average number of days during fall with thunderstorms.

bumpiness normally encountered in cumuliform clouds. A draft may be compared to a river flowing at a fairly constant rate, whereas a gust is comparable to an eddy or other type of random motion of water in the river. The difference between drafts and gusts is one of wavelength and duration, and there is no clear-cut dividing line between the two. The upper portion of the gust wavelength spectrum is also the lower portion of the draft spectrum. A draft to a small aircraft could be a gust to a large aircraft. Gusts are always *superimposed on drafts* in thunderstorms.

THE LIFE CYCLE OF THE INDIVIDUAL THUNDERSTORM

Individual thunderstorms are rarely larger than 10 miles in diameter, and their life cycle is from about 20 minutes to 1½ hours in duration. However, it is very common for thunderstorms to develop in clusters of two or more. Clusters, with individual thunderstorms at various stages of development, sometimes are over a hundred miles in diameter and last for 6 hours or more.

It is convenient to discuss the individual thunderstorm's structural characteristics on the basis of the three stages of its life cycle: cumulus (growth stage), mature, and dissipating (degenerating stage).

Cumulus Stage. Although most cumulus clouds do not become thunderstorms, the initial stage of a thunderstorm is always a cumulus cloud. The main feature of the cumulus or building stage is the updraft which may extend from near the earth's surface to several thousand feet above the visible cloud top (see fig. 87). The upward motion within the draft may vary in strength from point to point and from minute to minute. The greatest vertical speed occurs at higher altitudes late in this stage when it may reach 3,000 feet or more per minute.

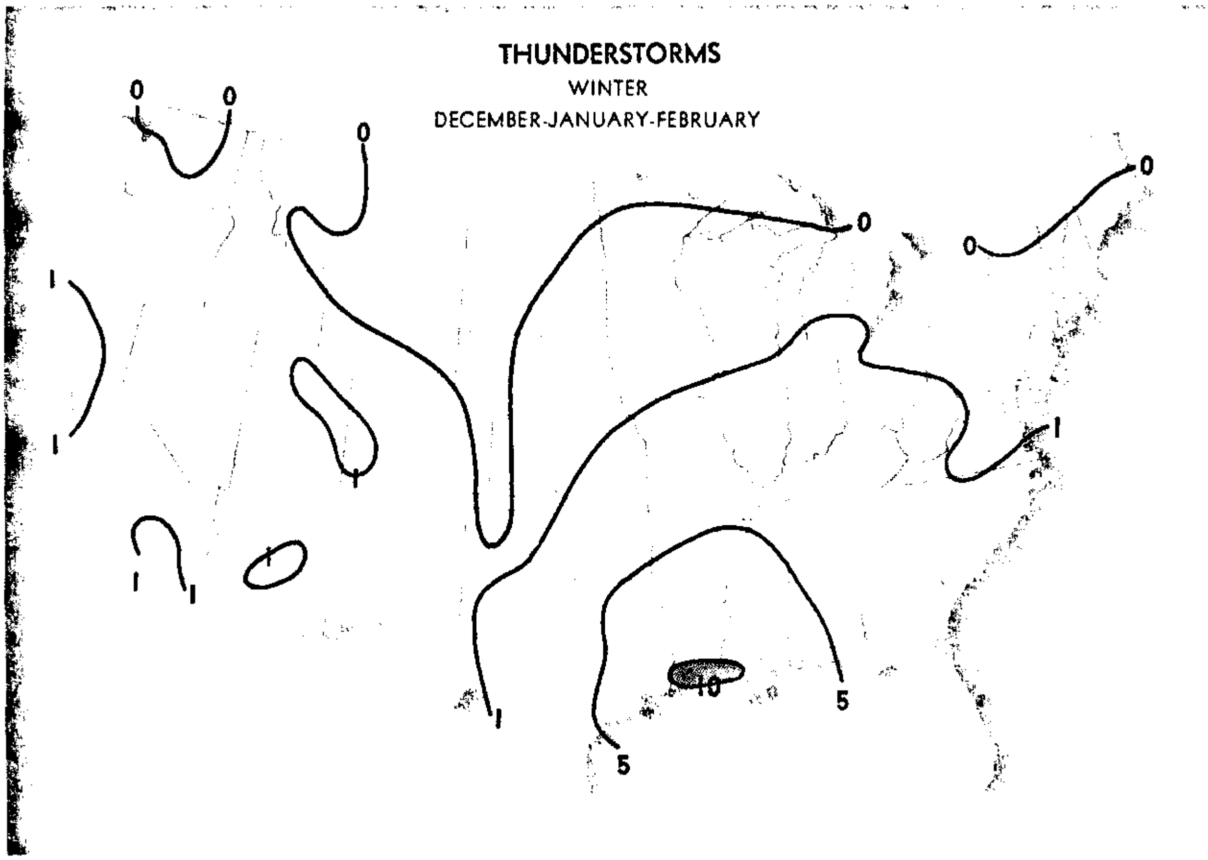


FIGURE 86. The average number of days during winter with thunderstorms.

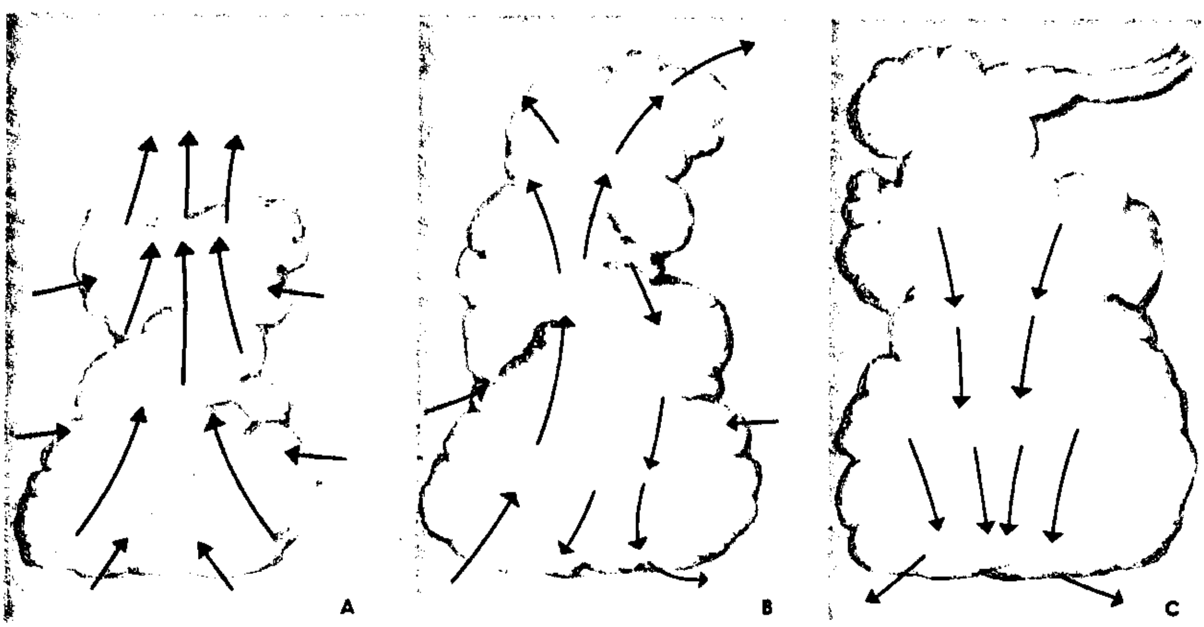


FIGURE 87. The stages of a thunderstorm.

The cumulus cloud meanwhile grows into a cumulonimbus.

During this early period, cloud droplets are very small but grow into raindrops as the cloud builds upward. The raindrops remain as liquid in the updraft to heights well above the freezing level, even to 40,000 feet in some storms. Still higher, the rain becomes mixed with snow, then changes to wet snow, and finally to "dry" snow. This change-of-state zone increases in depth as the updraft speed increases. There usually is no falling precipitation during this stage because the drops and ice particles are being carried upward, or are more or less suspended in the ascending air currents.

Mature Stage. The beginning of rain at the earth's surface initiates the mature stage of the thunderstorm. The raindrops and ice particles have grown to the extent that they can no longer be supported by the updrafts. This occurs roughly 10 to 15 minutes after the cloud has built upward to beyond the freezing level. In the mature stage, the cloud tops usually grow to 25,000 or 35,000 feet and occasionally break through the tropopause, reaching heights of 50,000 to 60,000 feet.

As the raindrops fall, they drag air with them. This is a major factor in the formation of the downdrafts which characterize every thunderstorm in its mature stage. The air being dragged downward by the falling raindrops is cooler than its surroundings, and, being unstable, its rate of downward motion is accelerated. Downdrafts develop in the middle regions of the cloud, and they gradually increase—first in depth and then in horizontal extent (see fig. 87B). Their speeds vary but may reach 2,500 feet per minute. The barrier presented by the earth's surface causes the speed of the drafts to decrease somewhat in their downward rush in the lower 5,000 feet of the atmosphere. The principal effect of the barrier, however, is to cause the downdrafts to spread out horizontally when they near the earth's surface (illustrated in fig. 88). The horizontal outflow of air produces strong and gusty surface winds and is usually accompanied by a sharp drop in temperature and a sharp rise in pressure.

Early in the mature stage, remaining updrafts continue to increase in speed, which may exceed 6,000 feet per minute. All of these hazards associated with the thunderstorm seemingly reach their greatest intensity at this time. Hail, if any, is most likely to occur during this stage.

Dissipating Stage. Throughout the mature stage, the downdrafts continue to develop and spread vertically and horizontally, while the updrafts are continually weakening. As a result of this action, the entire thunderstorm ultimately becomes an area of downdrafts (see fig. 87C).

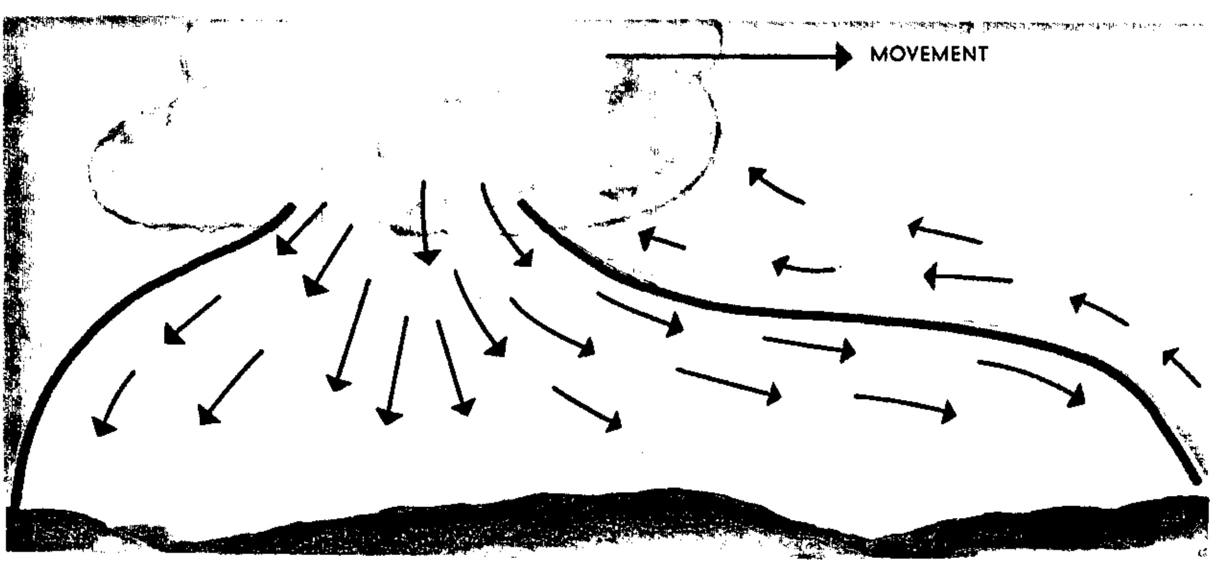


FIGURE 88. Winds near the ground accompanying a thunderstorm.

Because of the heating and drying process produced by the downdrafts, the rainfall gradually ceases, and the thunderstorm begins to dissipate. During this stage, the lower level of the thunderstorm frequently becomes stratiform in appearance, and its top develops the characteristic anvil structure. However, the appearance of an anvil is not in itself evidence that the thunderstorm is dissipating. Many times a thunderstorm with an anvil is producing severe weather.

On some occasions, the thunderstorm does not dissipate in the manner described above. If horizontal wind speeds increase markedly with height, the mature stage is prolonged, and considerable tilt develops in the updraft and cloud. In this situation, precipitation falls through only a small portion of the rising air and later falls through the relatively still air next to the updraft, or perhaps completely outside of the cloud. Since the drag of falling water is not imposed upon the rising currents in the cloud, the updrafts, in this situation, can continue until their source of energy is exhausted. The thunderstorm may then dissipate without going through a period when the principal vertical motion is downward. Furthermore, precipitation falling from the tilted cloud may produce downdrafts in the clear air outside of the cloud boundary. The dissipating stage is usually the most prolonged of the three stages of a thunderstorm.

THUNDERSTORM WEATHER

Thunderstorms are attended by severe or extreme turbulence, icing, lightning, thunder, and precipitation, and gusty surface winds. The more severe ones produce hail and sometimes tornadoes. Lightning is discussed in the section on thunderstorm electricity. Thunder, the sound emitted by rapidly expanding gases along the channel of a lightning discharge, is significant to the pilot in that it indicates the maturity of the storm.

HAIL

Hail competes with turbulence for first place as the greatest hazard to aircraft produced by the thunderstorm. Most, and perhaps all, thunderstorms have hail in the interior of the cumulonimbus cloud at some stage in their lives. In a large percentage of the cases, the hail melts before reaching the ground, but this does not lessen its danger to the pilot who encounters it aloft.

A single unit of hail, called a "hailstone," is found in the form of a ball or an irregular lump of ice, ranging from the size of a pea to the size of a grapefruit. Large hailstones usually have alternating layers of clear and cloudy ice.

Large hail is most commonly found in thunderstorms which have (1) strong updrafts, (2) large liquid water content, (3) large cloud drop sizes, and (4) great vertical height. It usually is produced during the mature stage of the thunderstorm's life span and is most frequently encountered at levels between 10,000 and 30,000 feet, but the frequency of large hail decreases quite markedly above 35,000 feet. Hailstones with diameters up to 5 inches have been reported at 29,500 feet. Hail may be found at any level within a thunderstorm and, on occasions, it is encountered in clear air outside of the storm cloud. Hailstones may be thrown upward and outward from the cloud for as much as 5 miles under an innocent-appearing anvil of cirrus clouds.

If strong updrafts can be avoided, the chance of encountering large hailstones is reduced. But this is not to say that hail can be avoided simply by escaping the strong updraft areas. Hailstones larger than one-half to three-quarters of an inch can cause significant aircraft damage in a few seconds. Figure 89 is a photograph showing an aircraft which has flown through a "hail" of a thunderstorm.

While there is risk of an encounter with hail in any thunderstorm, subtropical and tropical thunderstorms contain less hail than those in more northern latitudes. Hail seldom reaches the ground in the subtropics and tropics.

TURBULENCE

All thunderstorms are turbulent, and some are potentially destructive to aircraft. Almost any thunderstorm possesses the potential to pro-

FIGURE 89. Hail damage to an aircraft.

duce "severe" turbulence and the typical large ones may produce turbulence classified as "extreme." Those which create the most severe turbulence usually are the "hail producers." While considerable turbulence may be found anywhere in the thunderstorm, there is less chance for severe or extreme turbulence in the lower levels.

A distinction has been made between drafts and gusts, the principal movements of air within a thunderstorm, and it is now appropriate to explore their natures more fully and to learn more about the effects of thunderstorms on landing and takeoff operations.

Drafts. The study of the thunderstorm's life cycle revealed that drafts occupy virtually the entire region of the storm. Their direction depends on the stage of development. In the early stages, the motion is mainly upward, except on the outer edges of the storm where it is downward but weak; in the mature stage, there are both downdrafts and updrafts; and in the final stage, the motion, except in unusual cases, is generally completely downward.

Drafts may change the altitude of an aircraft flying through a thunderstorm. Often it is virtually impossible to hold an assigned altitude. Drafts are not necessarily dangerous to the aircraft structure, depending upon the amount of gustiness superimposed upon the drafts. If the aircraft is wholly contained within a draft and the draft is of relatively uniform speed, turbulence will be at a minimum if the pilot applies proper flight techniques. The greatest turbulence is likely to be encountered when traversing adjacent rising and descending drafts.

Gustiness is usually greatest in these shear zones between oppositely moving drafts.

The following conclusions concerning the strength of drafts may be drawn from data obtained from aerial research:

(1) Updrafts are strongest in middle and upper levels of the thunderstorm.

(2) Updrafts are generally stronger and larger in both horizontal and vertical extent than downdrafts. Downdrafts may constitute a serious flying hazard, since significant vertical velocities are sometimes present as low as 300 to 400 feet above the earth's surface. This suggests that great caution should be exercised if attempting to fly beneath the thunderstorm clouds, especially over irregular terrain.

(3) Strongest downdrafts aloft are found in middle levels of the thunderstorm (the "first gust," a strong downdraft reaching the ground, will be discussed later).

(4) Because of stronger drafts, aircraft are vertically displaced most in middle and high levels. Upward displacements of up to 6,000 feet have been encountered, but they more often are less than 3,000 feet. The same aircraft that was displaced 6,000 feet when entering the thunderstorm at middle levels was displaced only 1,600 feet when penetrating the same storm at a level of 6,000 feet.

(5) In the middle and upper levels of the thunderstorm, aircraft are displaced in the vertical more, on the average, by updrafts than by downdrafts. However, downward displacements of up to 8,000 feet have been measured.

Gusts. Superimposed upon the large-scale continuous flow of the drafts are the numerous, irregular, random, sudden, and brief turbulent motions called gusts. These gusts have a significant effect upon aircraft, causing pitch, yaw, and roll movements. The severity of a thunderstorm may be classified by the intensity and the frequency of its gusts. These eddies vary in size from only a few inches to whirling masses of air several hundred feet in diameter. They are produced by (1) the shearing action between the drafts which are going upward and those which are going downward, and (2) the lifting action.

The characteristic reaction of an aircraft intercepting a series of gusts is a number of sharp accelerations or bumps which alter the position and altitude of the aircraft in an irregular pattern. The degree of turbulence experienced is related to (1) the number of such abrupt changes in the wind field encountered in a given distance, and (2) the strength of the individual changes. (See fig. 40 for the Turbulence Criteria Table based on derived gust velocities.)

In-flight research on thunderstorm gusts has shown the following:

(1) Gusts occurring with a greater frequency than 6 per 3,000 feet of horizontal distance are associated with extreme turbulence.

(2) Light (slow-speed) gusts are more frequent in all areas of the thunderstorm than strong (high-speed) ones, but strong gusts are found at all altitudes and, therefore, are unavoidable when penetrating thunderstorms.

(3) Vertical velocities as large as *200 feet per second* often occur in severe thunderstorms; a vertical velocity of 208 feet per second actually has been measured.

First Gusts. Another significant thunderstorm hazard is the rapid change in wind direction and speed which occurs near and at the surface immediately before the passage of the storm. This initial wind surge is called the "first gust," or "plow wind." It is particularly hazardous when aircraft attempt to land or takeoff in the face of a thunderstorm.

The strong, gusty wind results from the horizontal spreading out of the thunderstorm's downdrafts as they approach the surface of the earth. The first gust usually is the strongest wind observed at the surface during the thunderstorm's passage. In extreme cases, it may approach 100 knots and change the direction of wind 180° from that of the previously prevailing direction. However, first gust speeds average about 15 knots over prevailing speeds and about a 40° change in direction of the wind. The total first gust speed is the sum of the speed of the horizontally spreading downdrafts and the forward speed of the thunderstorm. Thus, speeds at the leading edge of the storm are considerably greater than those at the trailing edge.

Usually the extremely turbulent first gust precedes the arrival of the thunderstorm's roll cloud, if present, and the rain shower (see fig. 90). It often stirs up dust and debris, making its approach easily visible.

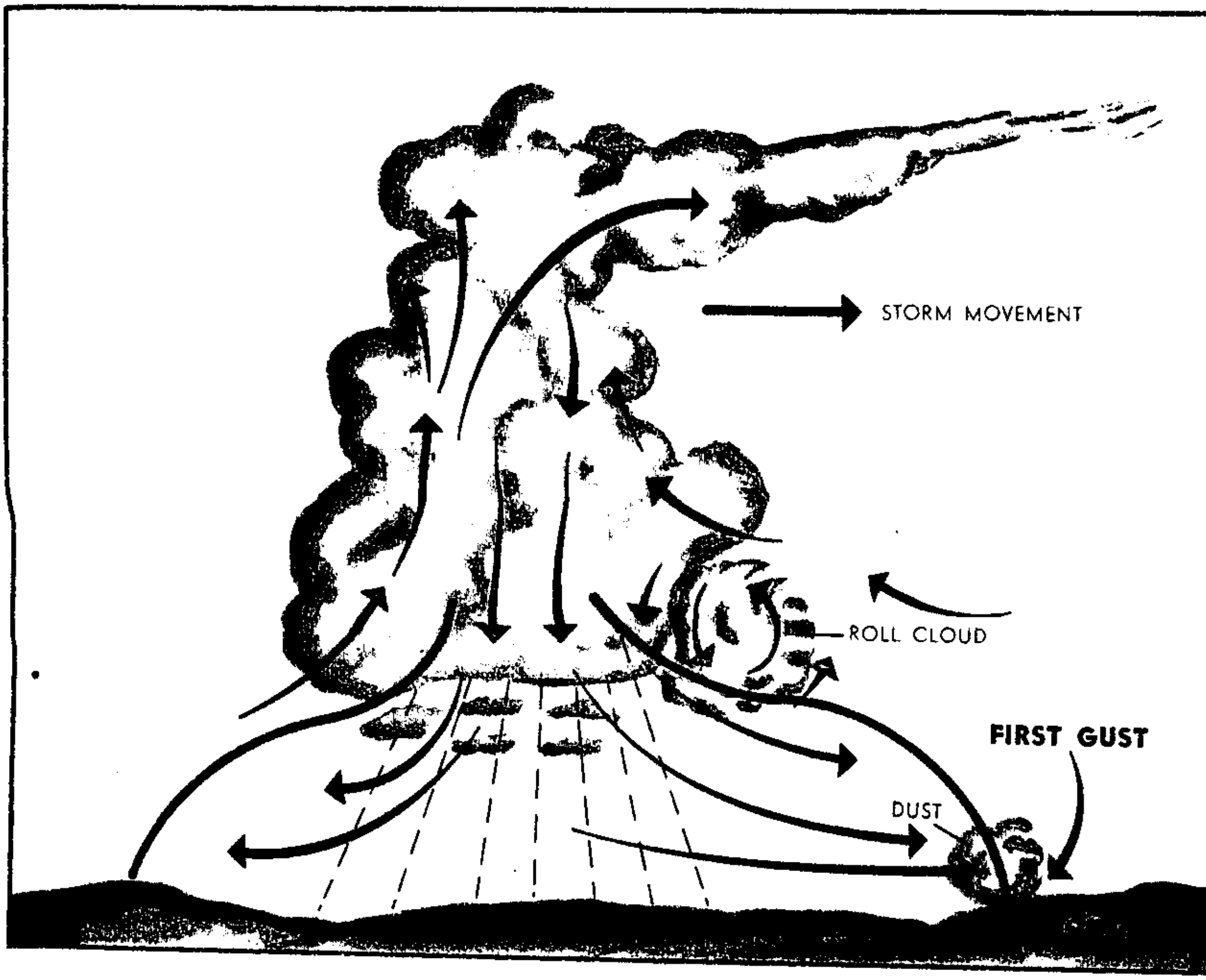


FIGURE 90. Air currents leading to the thunderstorm's first gust.

Strong, gusty wind will last for a few minutes after the thunderstorm's passage because the down-rush of air is spreading out in all directions as shown in figure 91. This wind condition, however, is not as dangerous as the first gust.

RAIN AND SNOW

The thunderstorm contains considerable quantities of liquid water, but this moisture is not necessarily falling to the earth as rain. Water drops are carried aloft by the updrafts, or may be suspended in them. Rain is encountered below the freezing level in almost all penetrations of mature thunderstorms. Above the freezing level, there is a sharp decline in the frequency of rain, but a mixture of snow with supercooled raindrops may be encountered. In-flight investigations have shown that moderate and heavy snow occur most frequently near the 20,000-foot level.

There may be a correlation between turbulence and precipitation. The intensity of turbulence, in many cases, varies directly with the intensity of precipitation. This relationship indicates that most rain and snow in thunderstorms is held aloft by drafts.

When rain showers reach the earth, they usually are heavy enough to cause a low ceiling and poor visibility. This further complicates landing and takeoff operations.

ICING

Clear icing in cumulus clouds and thunderstorms usually is limited in extent because these clouds, although of great vertical height, are

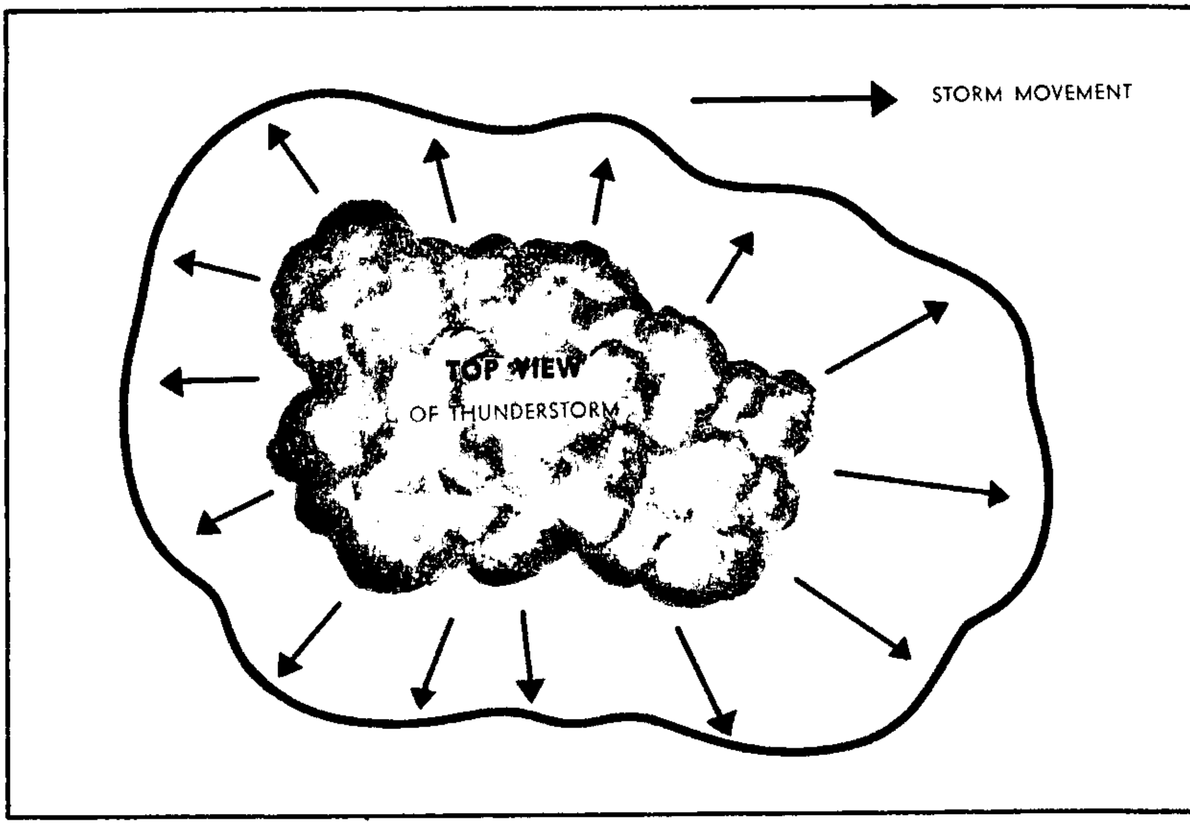


FIGURE 91. Surface winds resulting from thunderstorm downdrafts.

not very broad except when in clusters. But ice can accumulate rapidly. The heaviest icing conditions usually occur just above the freezing level where the greatest concentration of supercooled water drops exists, but severe icing may occur at any point above the freezing level at temperatures from 0° C. to −10° C. Rime ice often accumulates rapidly on leading edges of aircraft flying through wet snow. Since the freezing level is also the zone where severe turbulence and rain most frequently occur, this particular altitude appears to be the most hazardous.

In areas where individual thunderstorms are isolated or scattered, icing usually does not present too serious a problem because the flight time in each storm is relatively short. In areas of numerous thunderstorms, the icing problem may be serious if the aircraft has prolonged exposure to icing conditions. Also, icing is encountered sometimes in the anvil tops. Aircraft icing will be discussed further in the next chapter.

PRESSURE VARIATIONS

The pressure variations generally associated with thunderstorms are (1) a rapid fall as the storm approaches, (2) an abrupt rise with the onset of the first gust and arrival of rain showers, and (3) a gradual return to normal pressure as the storm moves on and the rain ceases. This cycle of pressure change may occur in 15 minutes. If the altimeter setting is not corrected, the indicated altitude might be in error by over 100 feet.

THUNDERSTORM ELECTRICITY

The electricity generated by a thunderstorm is rarely a great hazard to aircraft from the standpoint of safety, but it may cause damage, and it tends to annoy flight crews. Lightning is obviously the most spectacular of the electrical discharges produced.

LIGHTNING

The estimated electrical potential difference required to produce a flash of lightning to the earth is of the order of 100 to 200 million volts. The electric currents in the return strokes to the cloud are the major components of the flash, and the peak values of these currents range from 5,000 to 500,000 amperes. A flash may have many return strokes occurring so quickly that they give an impression of a flickering discharge. However, the average number of return strokes in a flash is four. Flashes of lightning within a cloud or between adjacent clouds occur more frequently in most thunderstorms than do flashes of lightning to the earth. The peak electric currents of these cloud flashes are believed to be about one-tenth as great as those of flashes to the Earth.

Strokes to aircraft often perforate the skin and damage electronic equipment. Occasionally a stroke to a nonmetallic surface causes damage to the frame of the aircraft. There is some suspicion that in rare instances a lightning strike could cause ignition of vapors in the aircraft fuel system. Accordingly, fuel systems are designed to provide protection against this possibility. Nearby lightning can be hazardous even though it does not strike the aircraft. It can induce a permanent error in the reading of the magnetic compass. It can momentarily distract or blind a pilot and interfere with his control of the aircraft. The loud blast of radio static produced by a lightning flash affects radio receivers on low and medium frequencies even when the flash occurs many miles away.

Following are some of the more common relationships between lightning and the thunderstorm cloud.

(1) The thunderstorm clouds usually build upward to an altitude where the air temperature is about —20° C. before the onset of lightning.

(2) Once lightning has begun in a thunderstorm, it usually continues even though the tops of the clouds may subside to lower levels and higher temperatures.

(3) Flashes of lightning occur more frequently within a cloud or from one cloud to another cloud than from clouds to the Earth.

(4) The frequency of lightning flashes reaches a maximum as the thunderstorm clouds attain their greatest height. The most extensive horizontal flashes occur in the mature stage of the thunderstorm at elevations extending from the freezing level upward to where the temperature is —10° C. Although flashes of lightning may occur throughout a thunderstorm cloud, the more energetic and severe flashes to the earth are usually terminated only in the lower portions of the cloud.

(5) As the overall height of the thunderstorm decreases after it reaches maturity, the frequency of the flashes decreases. However, the strength or severity of an individual flash may remain great.

(6) The period of the greatest frequency of lightning is often followed immediately by the period of heaviest rainfall. The exact mechanisms which produce the large electric potential are not completely understood, but they are believed to operate most effectively where liquid water and crystals of ice or snow coexist within the clouds.

PRECIPITATION STATIC

Precipitation static, a steady, high level of noise in radio receivers caused by intense, continual corona discharges from sharp metallic points and edges of flying aircraft, is encountered often in the vicinity of thunderstorms. When an aircraft flies through an area which contains clouds, precipitation, or a concentration of solid particles (ice, sand, dust, etc.), it accumulates a charge of static electricity. The electricity discharges onto a nearby surface, or into the air, causing a noisy disturbance at lower radio frequencies. Certain techniques can minimize the interference, for example, the incorporation of wick discharges, and antistatic antenna hardware can usually reduce the static to a tolerable level. Practically speaking, precipitation static does not interfere with reception on ultra-high frequencies.

The corona discharge is weakly luminous and may be seen at night under certain conditions. In itself, it is harmless. It was named "St. Elmo's fire" by Mediterranean sailors, who frequently saw the brushy discharge at the top of ship masts.

Precipitation static near or within thunderstorms, tends to be most severe in the region where the greatest weather hazards to aircraft are present—that is, near the freezing level where snow changes into rain or rain into snow, and severe turbulence and updrafts and downdrafts are present.

CLASSIFICATION OF THUNDERSTORMS

As previously indicated, the lifting action necessary for thunderstorm formation may be furnished by (1) any type of front, (2) mountainous terrain, (3) convective currents, or (4) convergence. The latter three sources of lift can be found either within an air mass far removed from a front or, together or individually, in conjunction with a front. Thunderstorms which are far removed from fronts tend to be scattered or isolated; those associated with fronts tend to be more numerous and in lines. It is convenient, therefore, to identify them as either air mass or frontal thunderstorms. While it is not an infallible rule, the pilot can expect more numerous thunderstorms when they are called *frontal* than when they are called *air mass.*

FRONTAL THUNDERSTORMS

Since all thunderstorms are similar in physical makeup, it is unnecessary to describe separately the ones associated with each individual type of front. However, these are some differences worthy of comment:

1. Because of the gentleness of the frontal slope, stratiform clouds are likely to accompany warm fronts, and thunderstorms may be obscured unless the pilot is flying above the stratiform layer. If flying at low levels, the pilot may be forewarned of their presence by crash static in his earphones. Because of the shallow slope of the front, they are usually the least severe of all frontal thunderstorms.

2. Thunderstorms associated with cold fronts are normally the most severe ones found anywhere except in squall lines. They usually form in a continuous line and are easy to recognize by a pilot approaching the front from any direction. Their bases are normally lower than those of other frontal thunderstorms and they are most active during the afternoon.

3. Thunderstorms are often associated with a warm front type occlusion. In this case, they occur along the upper cold front and are set off by the rapid lifting of warm, moist air. They are more severe than warm front thunderstorms but, in similar fashion, are usually embedded in stratiform clouds.

SQUALL LINE THUNDERSTORMS

Thunderstorms along a squall line frequently are similar to those along a cold front and even more violent. The cloud bases are often lower and the tops higher than with most thunderstorms. The most severe conditions, such as heavy hail, destructive winds, and tornadoes are generally associated with squall line thunderstorms. Usually most intense during the late afternoon and evening, squall line thunderstorms may occur at any time.

Chapter 10 indicated that squall lines often develop about 50 to 300 miles ahead of and roughly parallel to fast-moving cold fronts. On some occasions, a line of thunderstorms (also called a squall line) develops immediately over a cold front, and then moves out ahead of the front. Squall lines usually form rapidly, and sometimes a series of them will develop ahead of the cold front, a new one springing up to take the place of one which moves out rapidly in advance and dissipates. Figure 92 is a photograph of a line of thunderstorms.

While squall lines frequently accompany cold fronts, the existence of a front is not a prerequisite. They may accompany low pressure troughs, the Intertropical Convergence Zone, shear lines, and easterly waves as discussed in chapter 21; or lines where sea breezes converge against mountain barriers (ch. 22). Other factors being favorable, squall line thunderstorms are most likely to develop in areas where there is a convergence of wind flow in the lower at-

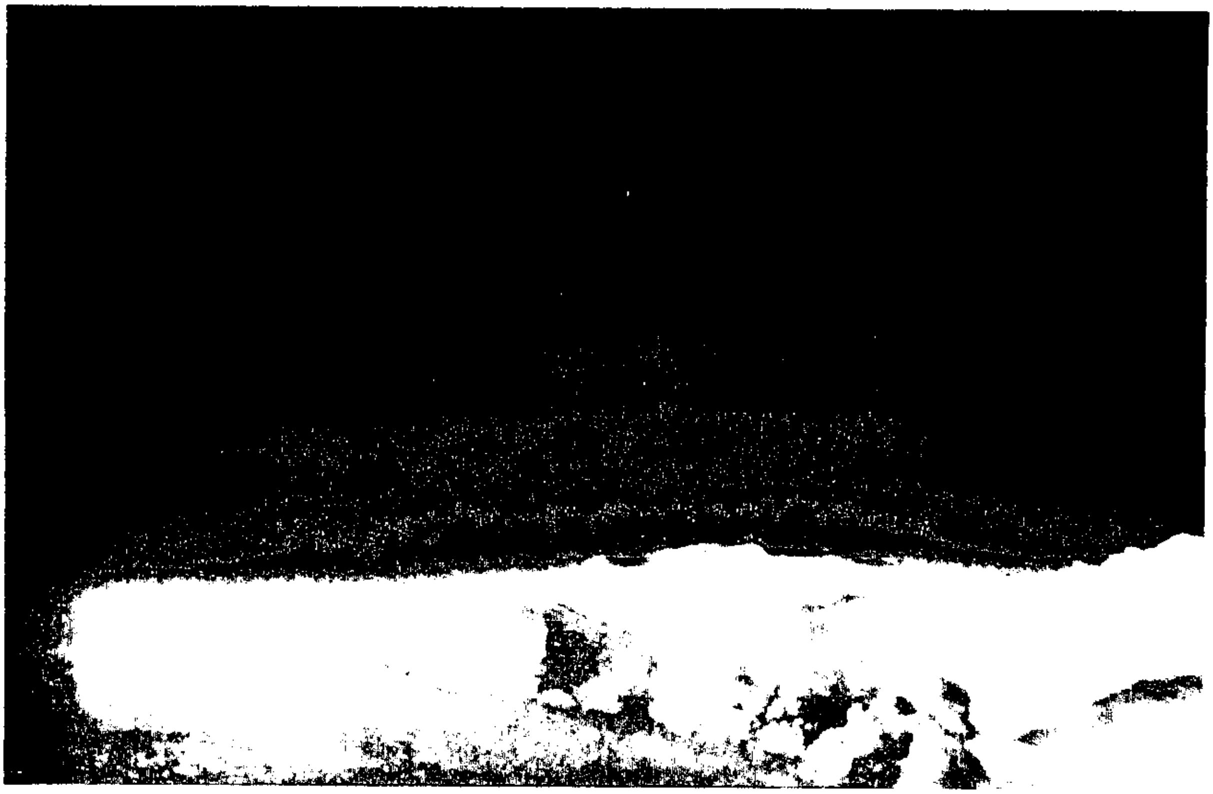


FIGURE 92. Squall line thunderstorms.

mospheric levels, regardless of the cause of the converging flow. Since such a condition can exist within an air mass, squall line thunderstorms, strictly speaking, are often air mass thunderstorms. However, air mass thunderstorms customarily mean to most people those thunderstorms meeting the description given in following paragraphs.

AIR MASS THUNDERSTORMS

The basic characteristics of air mass thunderstorms are the following: (1) they form within a warm, moist air mass and are in no way associated with fronts, and (2) they are generally isolated or scattered over a large area. Air mass thunderstorms may be classified as convective, orographic, or nocturnal.

Convective Thunderstorms. Convective thunderstorms may receive their necessary lift by heating from below or by convergence of the wind flow. An example of convergence in the wind flow within an air mass is a low pressure trough containing no fronts. If a line of thunderstorms develops in this zone, it is termed a squall line (see above). However, if the thunderstorms are scattered or isolated, most people would refer to them as air mass thunderstorms.

Those convective thunderstorms formed by convergence have no particular diurnal variation with respect to *time of occurrence*. However, they tend to be *most active* over land in the afternoon and early evening, and most active over water during the night and early morning. This diurnal variation in activity over land results from the assistance to development caused by solar heating, and over water, by radiation of the cloud tops.

Thunderstorms receiving their necessary lift only through heating from below seldom are found in an appreciable wind flow. Strong winds tend to break up the convective currents. Land-type convective thunderstorms normally form during the afternoon hours after the Earth has gained maximum heating from the sun. Al-

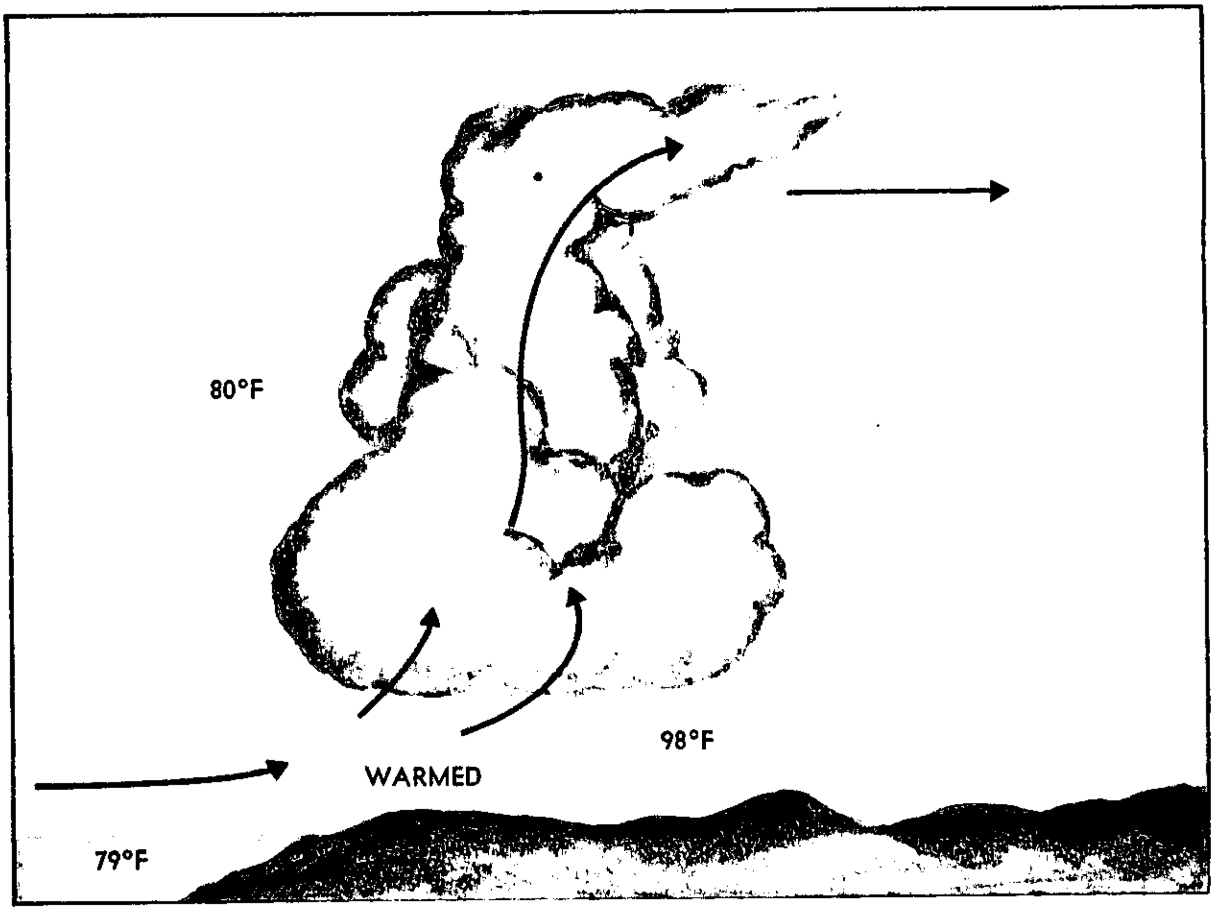


FIGURE 93. Convective coastal thunderstorms.

though they form as individual cumulonimbus clouds, they sometimes become so numerous over a particular geographical area that VFR flight is impossible. Such a condition normally lasts from 1 to 3 hours. This type of thunderstorm also develops over coastal regions during the afternoon if winds are light. Cool, moist air from the water is heated as it moves over the warmer land surface. In this case, the thunderstorms are a short distance inland from the shoreline. The reverse is true during the night and early morning hours, when cool air over the land moves over the warmer water surface, causing thunderstorms to form a short distance offshore. Convective coastal thunderstorms are illustrated in figure 93.

Orographic Thunderstorms. These develop when the wind forces moist, unstable air up mountain slopes. They tend to be more frequent during afternoon and early evening because heating from below is working in conjunction with the forced lifting. The storm activity is usually scattered along the individual peaks of the mountains, but occasionally there will be a long unbroken line of thunderstorms. Violent thunderstorms with hail are common in high mountains such as the Rockies.

Identification of orographic thunderstorms from the windward side of the mountain often is difficult. Stratus or stratocumulus clouds below the level of free convection frequently enshroud the mountains and obscure the storm clouds.

Nocturnal Thunderstorms. Although the term "nocturnal," meaning "occurring during the night," is sometimes applied to convective thunderstorms which form offshore as described above, it is more commonly applied to a peculiar type of air mass thunderstorm found in the Midwest. This type, among the most severe anywhere in the country, frequently occurs at night or early in the morning in the Central Plains area during late spring and summer. These thunderstorms are associated with unusually moist air aloft, but the mechanism which sets off their formation is not very well understood. It could be radiational cooling of cloud tops or a complex diurnal variation in the wind structure.

THUNDERSTORM INFORMATION FROM RADAR

Weather radar provides valuable information on thunderstorms, both by locating them and by revealing their intensity. It is especially effective in thunderstorm detection because hail, if any, and the large drops of water within thunderstorms give the strongest return signals (bright area on the Plan Position Indicator scope) of any type of weather (see fig. 94). Smaller droplets result in dimmer areas on the scope, while snow produces the faintest detectable echo.

A direct relationship exists between icing and turbulence potential and the strength of radar echoes. The sharpness of echo edges (strong echo gradients), and their vertical extent, and the rate at which the thunderstorm echo is building are related to thunderstorm severity.

Different types of radar equipment vary in their detection capability, but the Weather Bureau has installed advanced and very effective equipment in areas where thunderstorms occur frequently. Supplementing this radar network are the advanced radar sets of the Air Force and the converted military surplus sets which are used by the Weather Bureau in areas having relatively few thunderstorms.

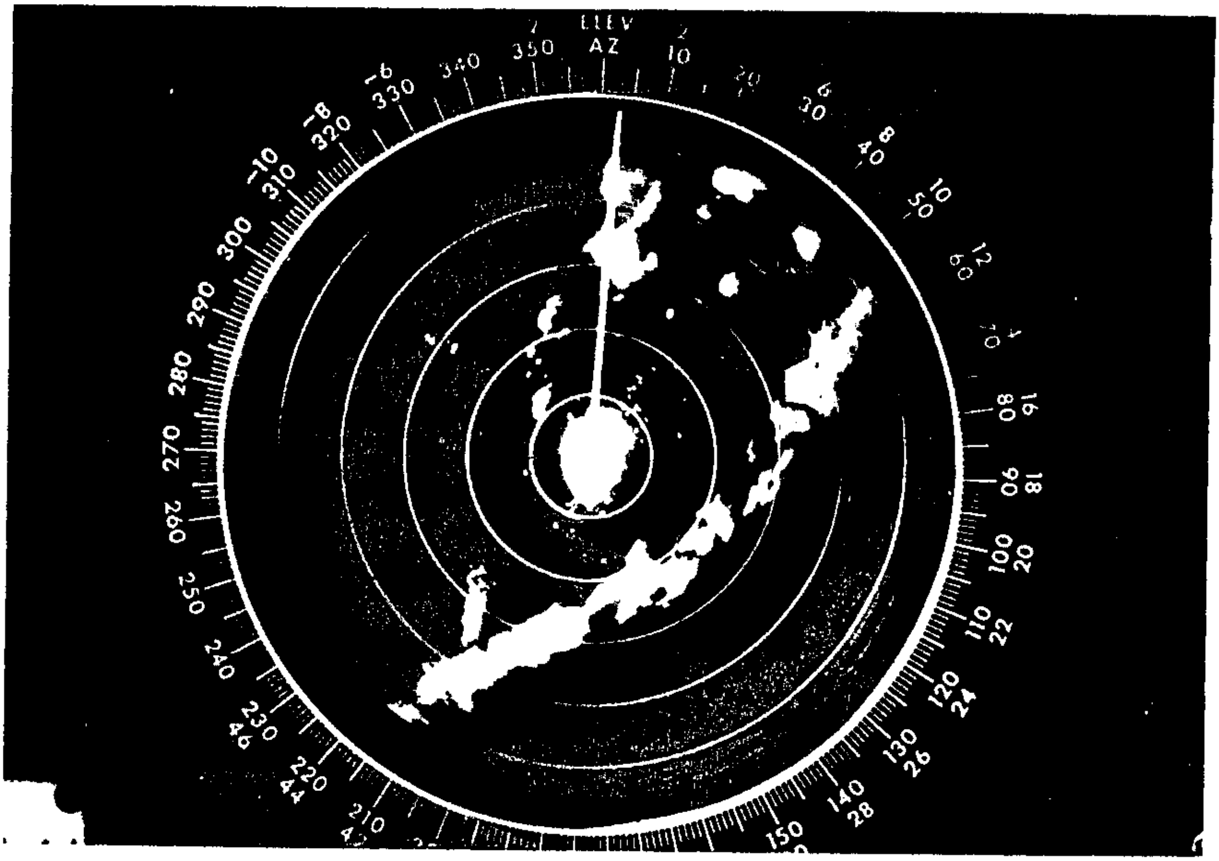


FIGURE 94. Radar photograph of a line of thunderstorms.

The following features, gleaned through interpretation of weather radar scopes, should be of particular interest to pilots:

1. A thunderstorm with radar echoes indicated to above 35,000 feet often contains extreme turbulence and hail.

2. Hazardous weather associated with scattered echoes usually can be circumnavigated. But if the lines or areas are reported as broken or solid and of moderate or strong intensity, hazardous weather can be avoided only if the aircraft is radar-equipped.

3. Severe clear air turbulence and hail may be experienced between thunderstorms if the separation between echoes is less than 30 miles.

Radar weather information is most valuable to the pilot when thunderstorms are numerous and when they are obscured in multiple cloud layers. However, echoes often change shape, character, and intensity in a matter of minutes, and current radar information received prior to takeoff may be worthless by the time thunderstorms are encountered. Airborne weather radar has become progressively popular in recent years largely for this reason. Figure 95 illustrates the manner in which a pilot makes use of the indications from weather radar equipment installed on his aircraft.

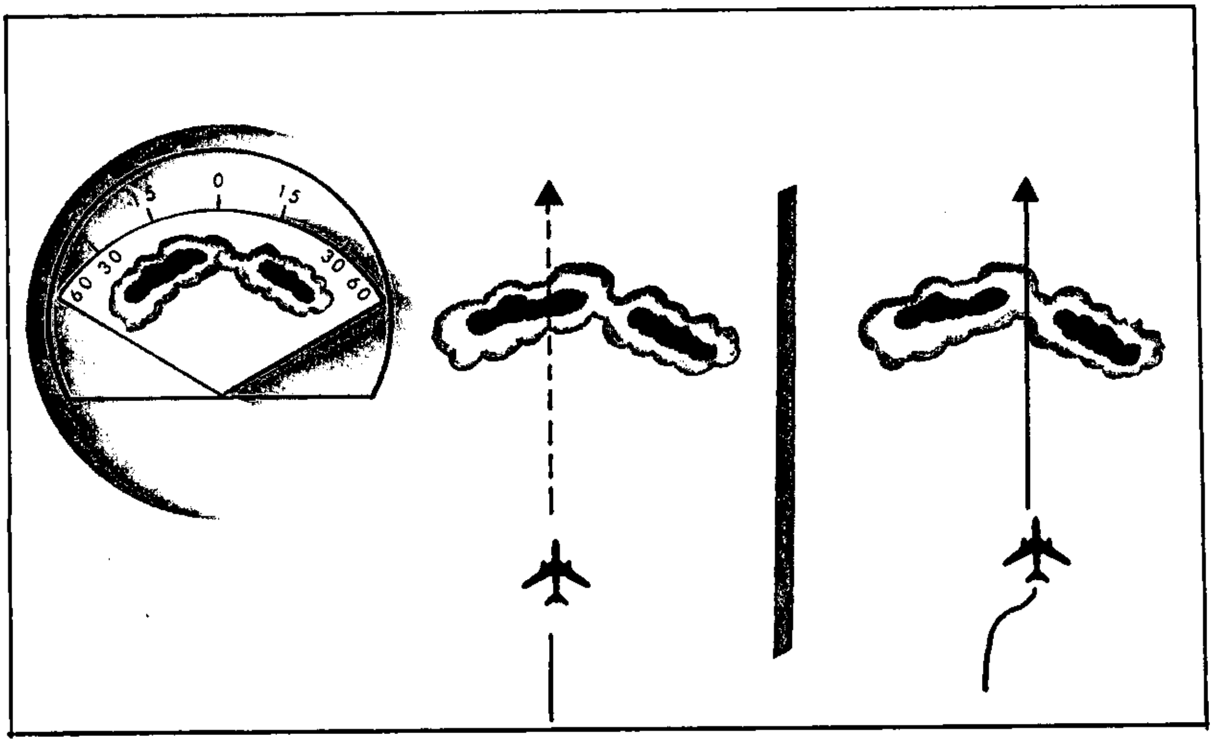


FIGURE 95. Airborne weather radar.

DO'S AND DON'TS OF THUNDERSTORM FLYING

The thunderstorm's many hazards to aviation and regions, within the "weather factory," where each hazard is likely to be most severe have been discussed. In concluding the chapter, it is appropriate to list some recommended practices for pilots in coping with these "uninvited guests" who insist on sharing the airspace. Unfortunately thunderstorms not infrequently occupy the "lion's share" of the route the pilot had hoped to follow.

Remember this: **So far as flying is concerned, no thunderstorm should be regarded as "light."**

The following recommendations are offered:

AVOID THUNDERSTORMS—THE BEST POLICY

1. Pilots, particularly those flying light aircraft, should avoid all thunderstorms.

2. Pilots, even those flying large aircraft, should avoid thunderstorms because the safety of the aircraft is not necessarily related to its size.

3. Pilots when flying around thunderstorms should not venture closer than 5 miles to any mature visible storm cloud with overhanging anvils because of the possibility of encountering hail.

4. Pilots should not attempt to fly under orographic thunderstorms even if the area on the other side of the mountains can be seen. Wind flow sufficiently strong to give the necessary lifting action to produce the thunderstorms will probably also create dangerous turbulence between mountain peaks. This turbulence, together with downdrafts, could result in disaster.

5. Pilots should avoid flying under any thunderstorm if possible because of updrafts under growing storms and downdrafts which can be quite strong in the rain core.

GO OR NO GO?

A decision of whether or not to risk engulfment by thunderstorms in areas where thunderstorms are known to exist should be based upon the following:

(1) Experience in flying through thunderstorms.

(2) The type of aircraft and the amount of stress it can stand.

(3) Whether or not the aircraft is radar-equipped.

(4) The vertical extent and physical appearance of the thunderstorm clouds.

With respect to item (4), any thunderstorm indicating echo tops of 35,000 feet or higher on ground-based radar should be avoided, regardless of other considerations, because of the extreme severity of hazards associated with them.

The pilot with airborne weather radar should remember that *radar does not eliminate the hazards* of the thunderstorm. It merely helps to locate the most severe conditions at the instant. Since the radar scope indicates only precipitation areas within thunderstorms, hazards can be encountered even in "soft spots." Thunderstorms having frequent, vivid lightning discharges usually are especially dangerous.

It is recommended that airborne weather radar be used as a thunderstorm *avoidance* rather than as a thunderstorm penetration tool. If circumnavigating individual storm clouds in a thunderstorm area, the pilot should frequently tilt his antenna in anticipation of the possibilities of hail beginning to fall from above and/or rapid growth of cumulonimbus clouds beneath him. These things can make "hard spots" rapidly at his flight level of what were "soft spots" a few moments earlier. He also should change the radar occasionally to maximum range in order to see what is behind the echo pattern he sees on short range. The pilot should take time to properly evaluate scope indications and watch for trends in echo patterns.

The pilot without airborne weather radar should make no attempt to find "soft spots" on the basis of any radar information which is not right up-to-the-minute. Vectoring information should be obtained only by direct contact with a ground-based radar operator who is evaluating his scope indications as he provides advice. Since storm vectoring service is limited to a very few areas, the pilot without airborne radar has only his judgment to tell him the best place to enter the thunderstorm. A thunderstorm cloud which is "boiling up" or growing rapidly generally contains more hazards than one which is showing little change. The first 15 minutes after the towering cumulus cloud in its upward growth has penetrated the freezing level is the time in the thunderstorm's life span when it normally offers its greatest hazards. The anvil stage may persist for several hours.

In making his decision of *go* or *no go*, the pilot might well consider that it is better to get to his destination late than not at all; 180° turns have saved many lives.

IF THE DECISION IS TO GO

It is suggested that the pilot engage in the following practices which have proven beneficial:

1. *Turn up the cockpit lights* to the highest intensity. Dark glasses often are used to avoid temporary blindness from lightning flashes.

2. *Establish penetration altitude.* Avoid altitudes from the freezing level upward to —10°

C. (roughly 5,000 feet above the freezing level). This usually is the most severe region of the thunderstorm. If information on the height of the freezing level was not obtained prior to takeoff, request it from the traffic controller or Flight Service Station. The "softest" altitude in a thunderstorm cloud is usually between 4,000 and 6,000 feet. Four thousand feet above the highest terrain in the area should be the minimum penetration altitude.

3. *Change airspeed* to the manufacturer's recommended airspeed for turbulent air penetration. This reduces the structural stresses resulting from turbulence and is best for maintaining control.

4. *Change power settings* to establish the reduced airspeed *before entering* the storm.

5. *Keep constant power settings in the storm.* This is recommended because the airspeed indicator gives false readings in vertical drafts or in heavy rain.

6. *Fly in a straight and level attitude.* Keep it as constant as possible, avoiding unnecessary maneuvering. This lessens the stresses imposed upon the aircraft.

7. If the auto-pilot is used, the *altitude hold mode* should be in the *off* position. If the altitude hold mode is left in the *on* position, the auto-pilot will place the aircraft in a "pitch down" attitude to compensate for an updraft and in a "pitch up" or "nose up" attitude to compensate for a downdraft.

8. *Pick a heading* that will take you through the storm in minimum time *and hold it.*

TORNADOES

Tornadoes occur with severe thunderstorms. They are violent, circular whirlpools of air shaped like an inverted funnel or tube hanging from a cumulonimbus cloud. These violently rotating columns of air range in diameter from about 100 feet to one-half mile (see fig. 96). Tornadoes do not always reach the ground, but, when they do, they are the most destructive of all atmospheric phenomena on a local scale. Sometimes, they descend very erratically, reaching the ground at some points along their paths and completely missing others. Their paths over the ground are often only a few miles long, and they move at speeds of 25 to 50 knots. Technically, they must reach the ground to be called tornadoes. When the funnel extends from the cloud but does not reach the ground, it is called a "funnel cloud."

The great destructiveness of tornadoes is caused by the very low pressure in their centers and the high wind speeds. Although greatest tornado wind speeds have never been measured precisely, property damage and other effects indicate that they may exceed 300 knots. Their very low pressure gives them great suction; they sometimes lift very heavy objects off the ground and have been known to suck water from creeks and small rivers. Tornadoes usually are dark in appearance due to the dust and debris they have sucked into their whirlpools. In the Northern Hemisphere, they rotate counterclockwise.

FIGURE 96. A funnel cloud aloft.

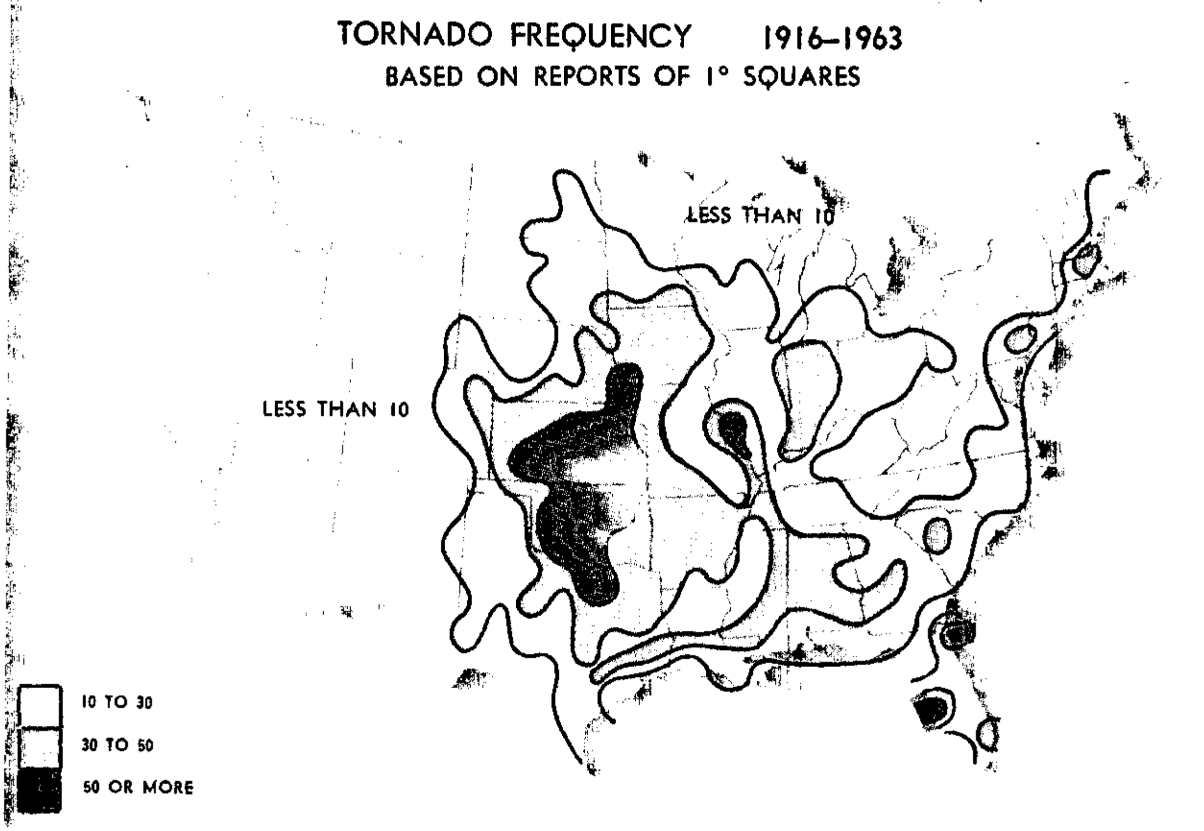


FIGURE 97. Tornado frequency, 1916–63.

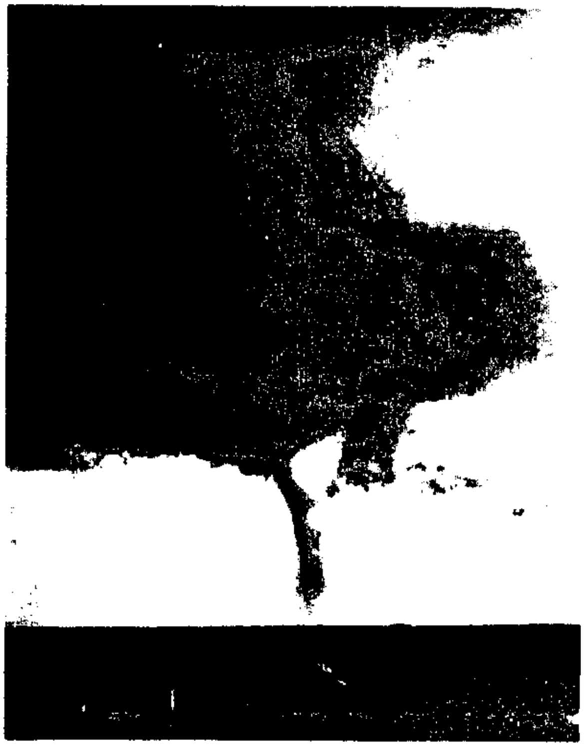


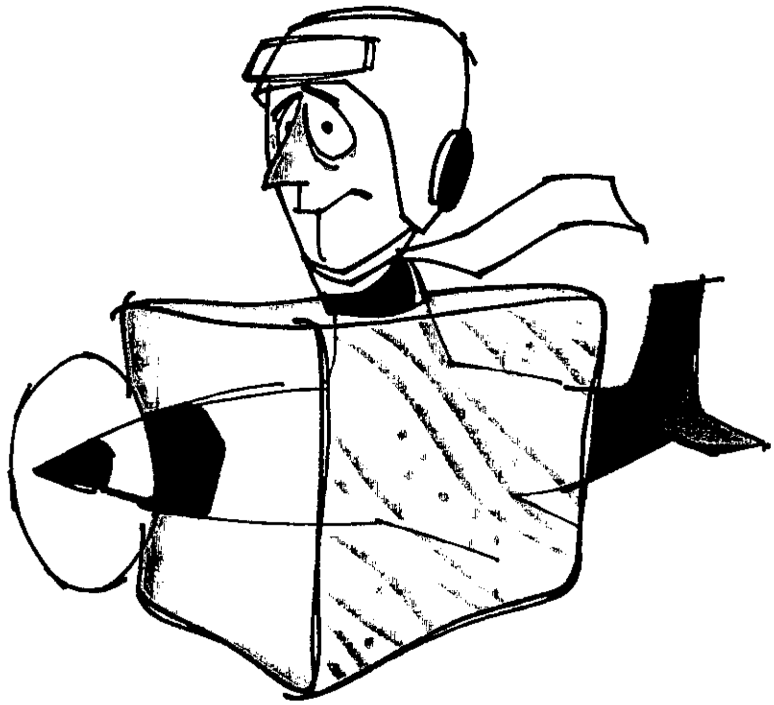
FIGURE 98. A tornado.

FIGURE 99. A waterspout.

Oklahoma, Kansas, Nebraska, and Iowa are the States of the United States which have the greatest number of tornadoes, but all of the contiguous States have observed them (see fig. 97). They occur more often with lines of thunderstorms than with those which are isolated.

A tornado over water is a "waterspout." Figures 98 and 99 are photographs of a tornado and a waterspout, respectively.

Tornadoes and waterspouts are easily seen, particularly at night if lightning flashes are frequent. Areas where tornadoes are reported or forecast should be circumnavigated if possible.



Chapter 12
ICING

Aircraft icing is one of the major weather hazards to aviation. Its formation on either fixed or rotary wings can dangerously disrupt the smooth flow of air, which reduces the aircraft's flying efficiency and capability. Another very significant hazard of ice accumulation is the vibration of structural components of the aircraft which at times can be disastrous. Ice which forms in the induction system literally tends to choke the engine by cutting off its air intake.

Other hazards to aviation which icing can create are loss of proper operation of control surfaces, brakes, and landing gear; loss of visibility from the cockpit to the outside; false indication on flight instruments; and loss of radio communication.

Aircraft icing can be classified into two main groups: structural and powerplant. These icing hazards will be discussed in detail, including the conditions which contribute to ice formation, its rate of accumulation, and the types of ice which result.

STRUCTURAL ICE FORMATION

Aircraft in flight are susceptible to structural icing when the free air temperature is 0° C. or colder, and there is either supercooled visible liquid moisture or an abundance of sublimation nuclei combined with high humidity.

FREE AIR TEMPERATURE

Wind tunnel experiments reveal that when saturated air flows over a stationary object, ice may form on the object when the air temperature is as high as 4° C. The temperature of the object is cooled by evaporation and pressure changes which result from the object disturbing the flow of air. Conversely, the object is heated by friction and, when the air is saturated, by the impact of water droplets. On an in-flight aircraft traveling at less than about 400 knots, these cooling and heating effects tend to balance. Therefore, structural ice may form when the free air temperature is 0° C. or colder. The most severe icing occurs with temperatures between 0° C. and —10° C. Icing is not uncommon, however, at temperatures between —10° C. and —25° C. and, on occasions, aircraft have encountered it at —60° C. and lower at high levels in thunderstorms and hurricanes.

Caution must be exercised in determining the free air temperature from the aircraft thermometer unless the pilot is reasonably sure of its accuracy or amount of error.

VISIBLE LIQUID MOISTURE

Clouds are the most common form of visible liquid moisture, but clouds of the cumuliform type are more apt to produce serious ice formation than others. Chapters 5 and 8 indicated that cloud droplets can remain in the liquid state at temperatures well below freezing. Being in an unstable state, these supercooled water droplets quickly turn to ice when they are disturbed by an aircraft passing through them.

The most dangerous icing conditions are usually associated with freezing rain; it can build hazardous amounts of ice in a few minutes.

SUBLIMATION

The sublimation process apparently is intensified when large quantities of suitable nuclei (see ch. 5) are present. The movement of an aircraft through an area of high humidity and high concentration of nuclei often triggers the sublimation process and results in a rapid accumulation of ice. Any layer of air at altitudes above the freezing level, even if clear, is a potential icing zone when its temperature-dew point spread is small. Icing is highly unlikely at temperatures below —40° C., however, because water vapor in the air tends to crystallize spontaneously at these temperatures.

ACCRETION RATE OF IN-FLIGHT STRUCTURAL ICING

The accretion (accumulation) rate of structural ice may vary from less than one-half inch per hour to as high as 1 inch per minute for brief periods of 2 to 3 minutes.

The factors influencing the rate of ice formation are (1) amount of liquid water, (2) drop size, (3) airspeed, and (4) the size and shape of the airfoil.

AMOUNT OF LIQUID WATER

Ice forms more rapidly in dense clouds than in thin ones. The rate at which ice forms and collects is directly proportional to the amount of supercooled liquid moisture in the air.

DROP SIZE

Small water droplets tend to follow the airstream as it is deflected by an airfoil; larger droplets or drops tend to resist this deflection. For this reason, large droplets or drops collect more easily and more rapidly on an exposed surface.

AIRSPEED

The rate of ice formation increases as airspeed increases up to about 400 knots. At airspeeds above 400 knots, the chances of ice formation gradually decrease because of the heat produced by skin friction. If ice forms, it usually melts

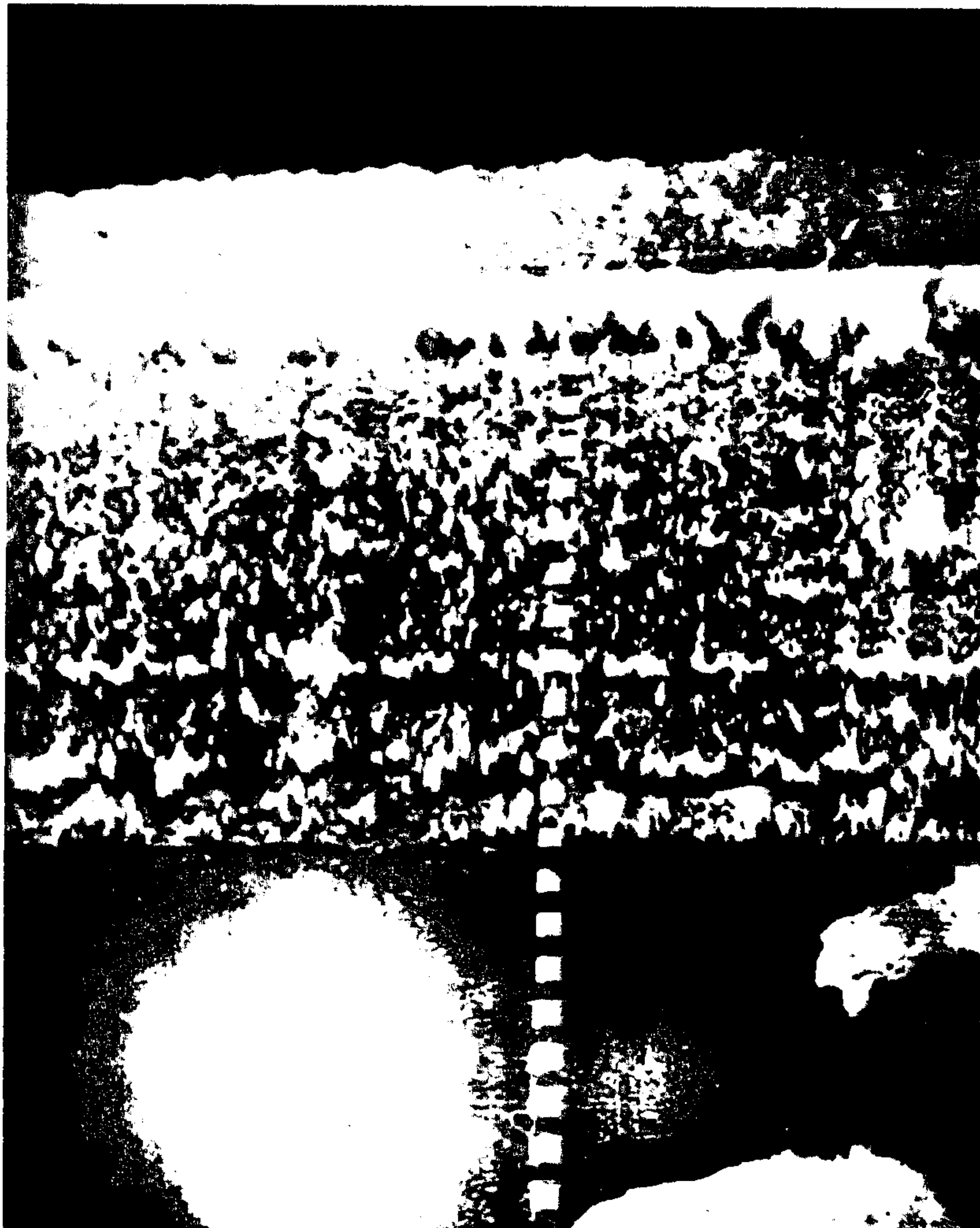


FIGURE 100. Clear wing icing (leading edge and underside) (courtesy Dean T. Bowden, General Dynamics/Convair).

rapidly. Structural icing is uncommon at airspeeds above 575 knots, but the airspeed at which frictional heating removes ice varies with the particular aircraft and the air temperature. A higher airspeed is necessary for ice removal at lower temperatures.

Altitude is also a factor involved in frictional heating; since air is less dense at high altitudes, frictional heating is less than at lower altitudes, other factors being equal. It is best for the pilot not to assume that he can alleviate an icing problem by increasing frictional heating.

SIZE AND SHAPE OF THE AIRFOIL

Ice forming on an aircraft is more likely to take the shape of the airfoil if the airfoil is thin, smooth, and highly streamlined than if it is blunt-nosed and/or rough. Once a coating of ice has already accumulated on the airfoil, it presents a larger collecting surface and accelerates further ice accretion.

TYPES OF IN-FLIGHT STRUCTURAL ICING

The physical characteristics of ice which accumulates on exposed surfaces of the aircraft depend primarily on the ice's accretion rate—that is, the type of ice which forms depends on the rate at which the drops or droplets strike the surface. Thus, the factors determining the type of ice which will form are identical to those determining the accretion rate. The types of ice are clear (glaze), rime, and frost.

CLEAR ICE

This is a transparent ice with a glassy surface (see fig. 100), identical to the glaze which forms on trees and other objects during a freezing rain. Clear ice can be smooth or rippled. It is smooth and streamlined when deposited from large supercooled cloud droplets or raindrops without solid precipitation. But if mixed with snow, sleet, or small hail it is rough, irregular, and whitish. The deposit then becomes very blunt-nosed with prominent and rough bulges building out against the air flow.

Clear ice usually forms on the leading edges of wings, antennas, engine cowlings, propellers, etc., in the shape of a blunt nose with gradual tapering toward the trailing edges. It is the most serious of the various forms of ice because it adheres so firmly to the aircraft and is very difficult to remove. Formed by the relatively slow freezing of large, supercooled water droplets, it tends to spread out and take the shape of the surface on which it freezes. Since very few air bubbles are trapped during the slow freeze, it is usually transparent.

Conditions most favorable for clear ice formation are high water content, large droplet size, temperature only slightly below freezing, high airspeed, and thin airfoils. Encountered most frequently in cumuliform clouds, clear ice also accumulates rapidly on aircraft flying in freezing rain or drizzle.

RIME ICE

As shown in figure 101, this is a milky, opaque, and granular deposit of ice with a rough surface. Rime ice is formed by the instantaneous freezing of small supercooled water droplets upon contact with exposed aircraft surfaces. This instantaneous freezing traps a large amount of air, giving the ice its opaqueness and making it very brittle. Rime ice usually forms on leading edges and protrudes forward into the air stream as a sharp nose. It has little tendency to spread over and take the shape of the airfoil.

Fast-freezing rime ice can accumulate when the temperature is anywhere between 0° C. and —40° C., but is most likely between —10° C. and —20° C. Most frequently encountered in stratiform clouds, it is also common in cumuliform clouds at temperatures below —10° C.

Rime ice is comparatively easy to remove by conventional methods, even though it distorts the airfoil much more than clear ice does. It frequently is encountered together with clear ice.

FROST

This is a light, feathery, crystalline ice structure of snowlike character (see fig. 102). It forms in flight when a cold aircraft descends from a zone of subzero temperatures to a zone of

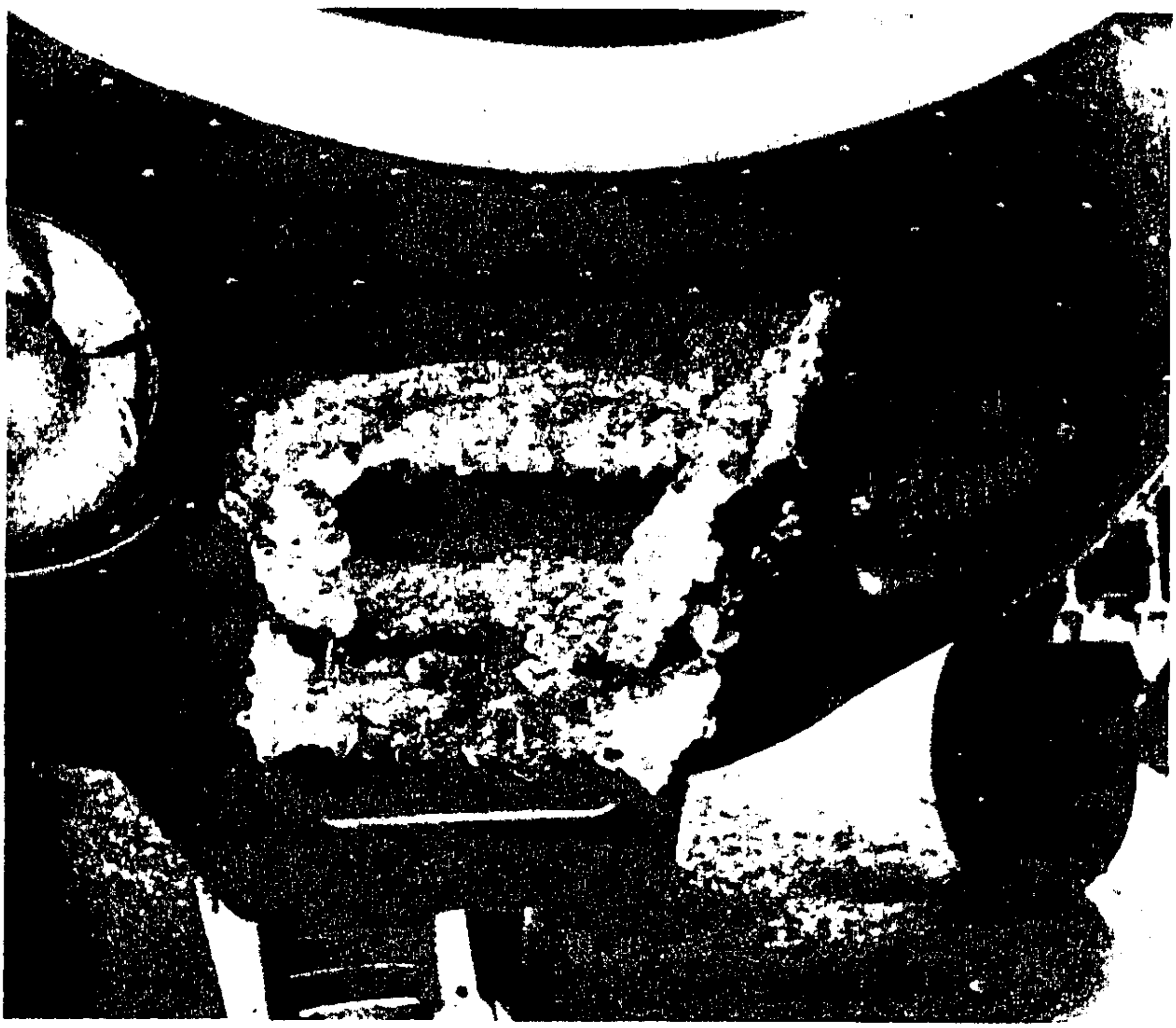


FIGURE 101. Rime icing on the nose of a Mooney "Mark 21" aircraft (photo by Norman Hoffman, Mooney Aircraft Inc., courtesy the *A.O.P.A. Pilot Magazine*).

above freezing temperatures and high relative humidity. The air is chilled suddenly to below freezing temperature by contact with the cold surfaces of the aircraft, and sublimation (formation of ice crystals directly from water vapor) occurs.

Windshields and glass canopies are especially susceptible to frost formation. This can be dangerous because visibility to the outside of the aircraft may be completely lost, and a pilot who has no experience in flying by instruments could find himself in a serious situation. Sometimes frost also forms on the cockpit side of windshields and canopies when visible moisture or high relative humidity exists. This is a definite hazard if no action is taken to prevent it.

Frost deposits are thin and sublimate or thaw off rapidly with continued flight in warm air.

EFFECTS OF IN-FLIGHT STRUCTURAL ICING

Although helicopters experience icing hazards equally as great or possibly even greater than those experienced by fixed wing aircraft, the discussion here will be limited to the latter. It

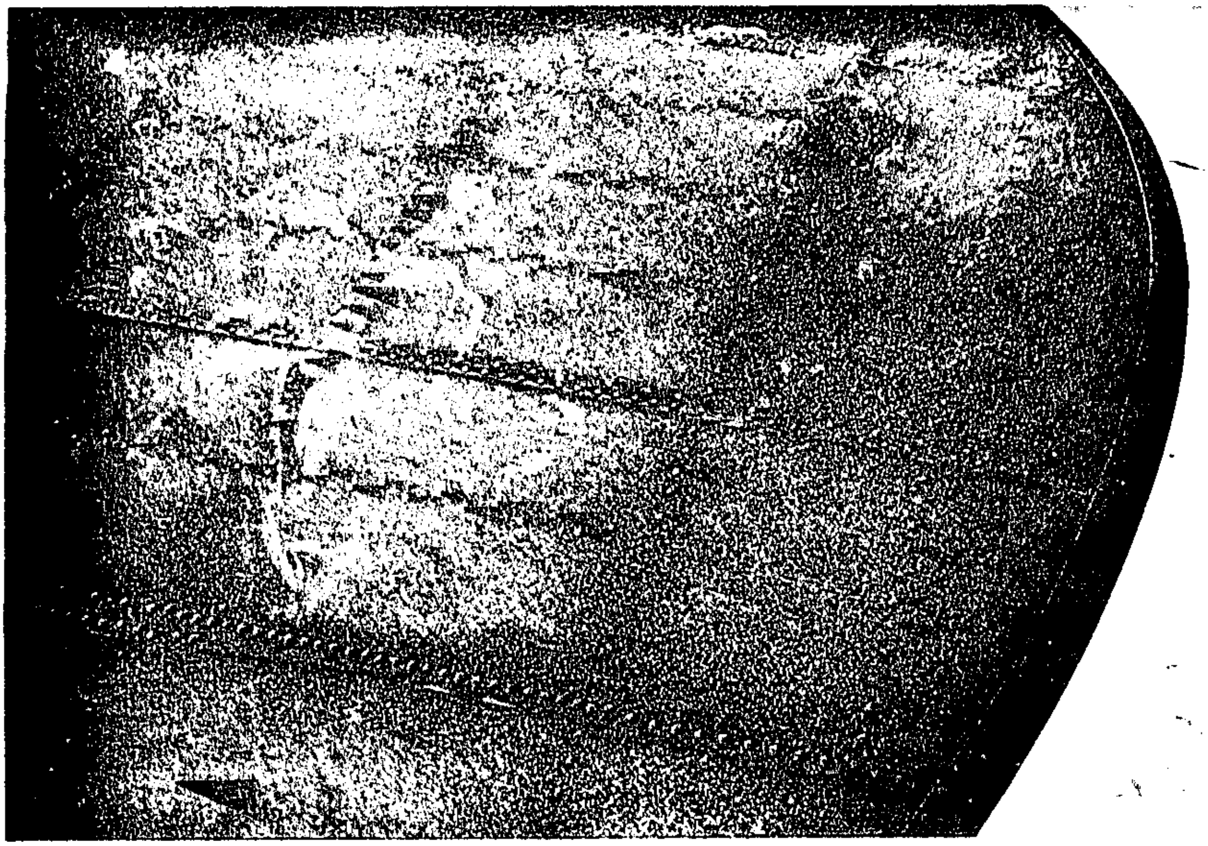


FIGURE 102. Frost.

would be desirable to include an account of the effects of icing on all types of vehicles which occupy the airspace, but that is beyond the scope of this publication.

WING AND TAIL SURFACES

Ice accumulations on wing and tail surfaces disrupt the flow of air around these airfoils. This results in a loss of lift, an increase in drag, and causes the aircraft to stall at a higher airspeed than normal (see fig. 103). The weight of the ice deposit presents less danger, but it also may become important when too much lift and thrust are lost.

Experiments have shown that ice deposits of only one-half inch on the leading edge of airfoils on some aircraft reduce their lifting power as much as 50 percent, increase the drag on the aircraft by an equal amount, and greatly increase the stalling speed. The serious consequences of these effects are obvious. And it should be remembered that one-half inch of ice or *more* can accumulate in a minute or two in some cases.

PROPELLERS

The accumulation of ice on the propeller hub and blades reduces the efficiency of the propeller, which in turn reduces airspeed. Increased power settings may then fail to produce sufficient thrust to maintain flying speed and more fuel is consumed.

An even greater hazard is the vibration of the propeller caused by the uneven distribution of ice on the blades. The propeller is very delicately balanced, and even a small amount of icing can create an imbalance. The resulting vibration places dangerous stress on the engine mounts as well as on the propeller itself. Propellers with low RPM (revolutions per minute) are more susceptible to icing than propellers

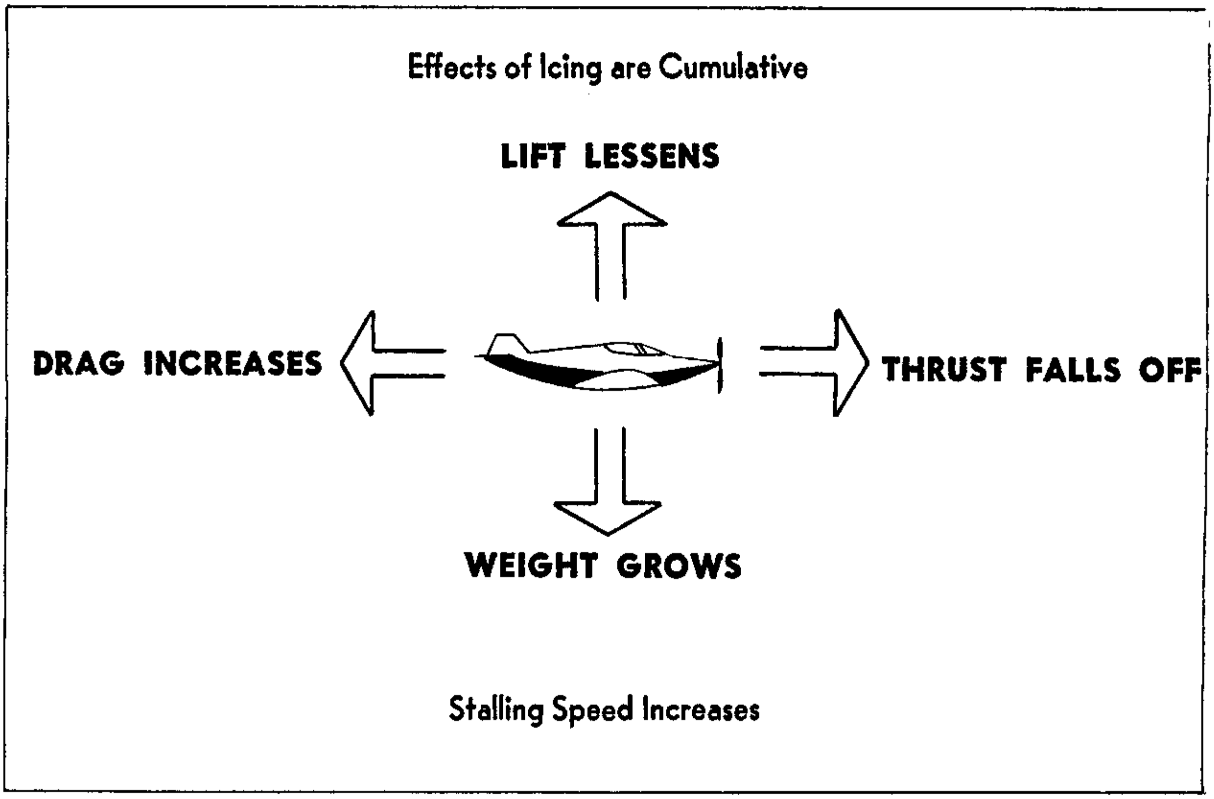


FIGURE 103. Effects of structural icing.

with high RPM. Ice usually forms faster on the hub of the propeller than it forms on the blades; it also forms first on the propeller hub.

Figure 104 is a photograph of an aircraft propeller which has accumulated ice in flight.

DROP AND TIP TANKS

On jet aircraft, ice usually forms first on drop and fuel tanks. Drop tanks are good collecting surfaces on other types of aircraft as well. The greatest effect of icing on these surfaces is to increase the drag on the aircraft.

PITOT TUBE AND STATIC PRESSURE PORTS

Icing of the pitot tube (see figs. 105 and 106) and other static pressure ports is dangerous because it causes inaccurate airspeed and altimeter readings. Other flight instruments depending upon the pitot static system, such as the rate-of-climb indicator and the turn-and-bank indicator, also become unreliable. This is a problem for any aircraft but even more of a problem for jet aircraft which have static ports on either side of the fuselage. When icing is observed on any part of the aircraft, the pilot should expect that the static ports are accumulating ice as fast or faster than other areas of his aircraft.

RADIO ANTENNA

The principal danger of an ice accumulation on the aircraft's radio antenna is the probable loss of radio communication. This is serious because the antenna is not likely to ice up unless other parts of the aircraft are also accumulating ice. The pilot, therefore, loses the ability to communicate when he needs it to request a change of altitude or to alter his course in order to get out of the icing zone as rapidly as possible.

WINDSHIELD

The formation of ice or frost on windshields is most frequent during takeoffs and landings, but it also occurs aloft. This can be tolerated by the pilot who is flying instruments until time for landing, when he obviously must have visual contact with the runway.

FIGURE 104. Propeller icing.

FIGURE 105. External icing on a pitot tube.

INTENSITIES OF IN-FLIGHT STRUCTURAL ICING

The amount of ice that an aircraft will accumulate in a given case depends considerably on the characteristics of that particular aircraft. Therefore, the intensity classifications which are given below are only general ones. They apply to clear and rime ice.

LIGHT

This is an accumulation of ice which can be disposed of by de-icing equipment. It presents no serious hazard for aircraft so equipped.

MODERATE

Ordinary de-icing methods provide only marginal protection in this icing condition. Ice continues to accumulate but not at a rate sufficiently serious to greatly affect the safety of the flight unless it continues over an extended period of time.

HEAVY

Ice continues to accumulate despite de-icing procedures. The rate of accumulation is fast enough to cause marked loss of airspeed and altitude, and is critical from the standpoint of flight safety.

STRUCTURAL AIRCRAFT ICING ON THE GROUND

Assuming that temperatures are favorable, the following are situations where ice forms on aircraft on the ground:

1. Freezing of any water which happens to be on the aircraft. This can affect the operation of control linkages and hinges, and otherwise makes attempts to fly the aircraft inadvisable before disposing of the ice.

2. Ice forming on exposed surfaces during taxi, takeoff, or landing as a result of splashing

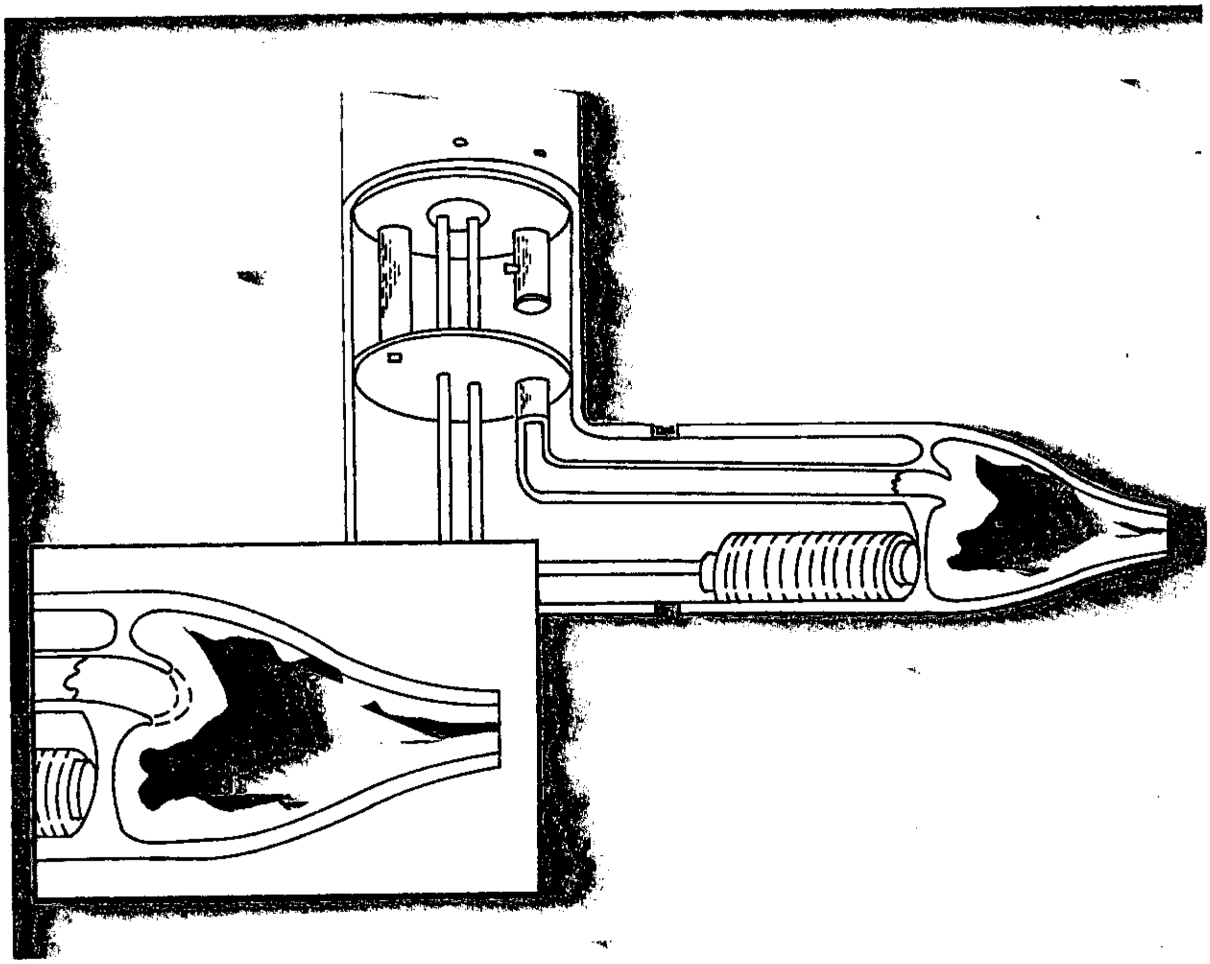


FIGURE 106. Internal pitot tube icing.

water or mud which may be on the taxi strip or runway. This could affect any exposed part of the aircraft, including the landing gear, flaps, brakes, control linkages and hinges, wings, tail surfaces, windshield, etc.

3. Glazing of the aircraft if left out of a hangar during freezing precipitation.

4. Frost collecting on the upper surfaces of the aircraft when it is parked outside overnight and the air is moist. Frost is very deceptive; it is usually quite thin and appears as if it would not affect the lift and drag of the aircraft as much as it does. It is a definite hazard during takeoff and *any frost is too much frost.*

5. Icing on the propeller during engine warm-up when the relative humidity is high.

STRUCTURAL DE-ICING AND ANTI-ICING

Military, airline, and a great many other aircraft have structural de-icing and/or anti-icing equipment. Many light aircraft do not have such equipment, especially those in normally warm weather areas such as Hawaii. The pilot who is about to fly an aircraft which is new to him into a cold weather situation should, prior to takeoff, check to determine exactly the extent of the aircraft's equipment to cope with icing.

Although it definitely is comforting to the pilot to know he has operable de-icing and anti-icing equipment, this is no assurance that it will solve all of his icing problems. Unless it is urgent that he reach his destination, it is still good advice to avoid icing conditions if possible. Structural ice can and often does accumulate on aircraft at a rate which makes most present day de-icing and anti-icing equipment largely, if not totally, ineffective.

The three common methods for eliminating ice are (1) mechanical, (2) use of fluids, and (3) heating.

MECHANICAL

This method makes use of rubber skins (boots) which are installed on the leading edges of wing and tail surfaces so as to fit the contour of the airfoil. Compressed air is cycled through ducts in these rubber boots, causing them to swell and change shape. The pulsating boot places stress on the ice deposit and cracks it. The air stream will then usually peel the ice off.

FLUIDS

This is an anti-icing method employed on rotating surfaces, especially propellers. The centrifugal force created by the rotation spreads the fluid evenly over the rotating surfaces. The fluids used for this purpose are very effective in preventing ice from adhering to the surface, and they are assisted by the centrifugal force which tends to throw the ice off as it forms.

HEAT

This is a comparatively new method which is used primarily as an anti-icer. Used mostly on airliners, heat is employed on some later models of military and business aircraft. In this method, the surfaces most susceptible to icing (wings, tail surfaces, and propellers) are heated as required by electrical means or by hot air which is piped from the engine manifold or jet engine compressor. Heat has been used for many years as both an anti-icer and de-icer for the pitot tube.

POWERPLANT ICING

In addition to the hazards potentially created by structural icing, an aircraft frequently is subjected to icing of the powerplant itself. The affected components are associated with supplying the engine with enough fuel which is mixed with air in the proper proportion for efficient combustion. Ice may form in either the air induction system or the fuel system but is a much more common occurrence in the former. Icing in the carburetor of piston engines is actually a combination of the two.

CARBURETOR ICING

This is a most treacherous ice accumulation which frequently causes engine failure without warning. It may form under conditions in which structural ice could not possibly form. If the relative humidity of the outside air being drawn into the carburetor is high, ice can form inside the carburetor in cloudless skies and with the temperature as high as 25° C. (77° F.). It is most serious when the temperature and the dew point approach 20° C. (68° F.), but pilots should be alert for it at any time the relative humidity is high. It sometimes forms with outside air temperatures as low as —10° C. (14° F.).

Carburetor ice forms during vaporization of fuel, combined with the expansion of air as it passes through the carburetor. Of the two cooling processes, vaporization of fuel causes the greater temperature drop, which may amount to as much as 40° C. (72° F.) but is usually 20° C. (36° F.) or less. But the temperature drop can occur in less than a second. Ice will form in the carburetor passages (fig. 107) if cooling is sufficient to bring the temperature inside the carburetor down to 0° C. or colder and if moisture is available. Ice may form at the discharge nozzle, in the venturi, on and around the butterfly valve, or in the curved passages from the carburetor to the engine.

The carburetor heater is an anti-icing device which preheats the air before it reaches the carburetor, melting any ice or snow entering the intake and keeping the mixture above the freezing point. The heater is usually adequate to prevent icing, but it will not always clear out ice which has already formed. During long glides

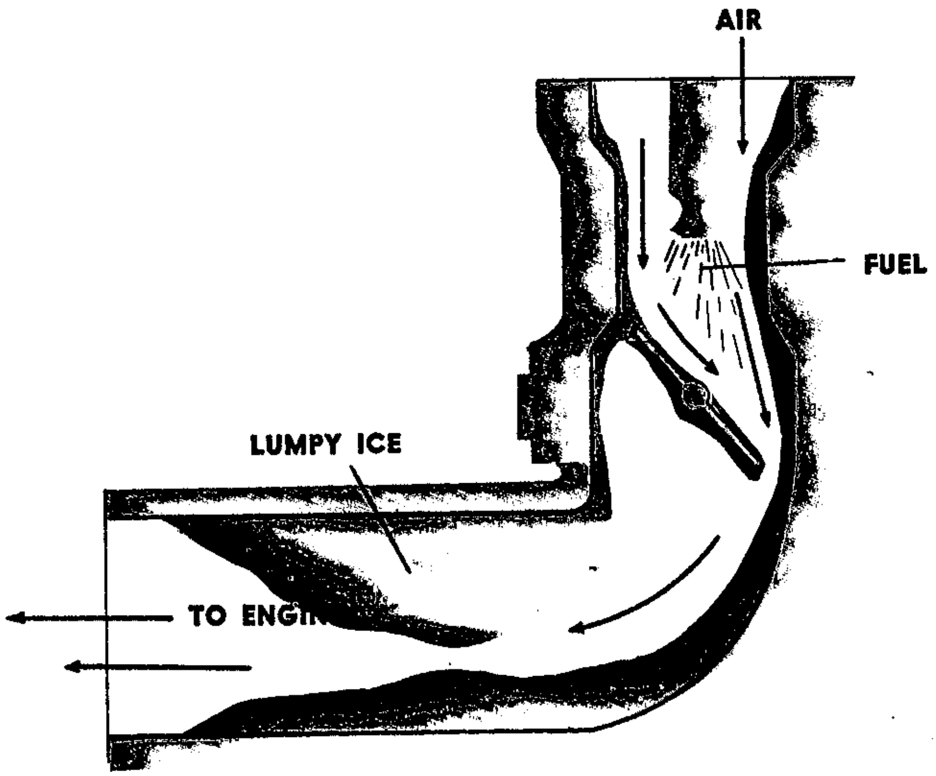


FIGURE 107. Carburetor icing.

with closed throttle, the carburetor heater may not prevent icing unless the throttle is opened periodically to keep the engine warm. Preheating the air tends to reduce engine power output and to increase operating temperatures. Therefore, the use of carburetor heat is not suggested on warm, dry days (when the engine may overheat), nor on takeoff unless weather conditions require it.

OTHER POWERPLANT ICING IN CONVENTIONAL AIRCRAFT

Fuel Tank Vent. Even though fuel tank vents are designed to prevent the accumulation of ice, it is conceivable that under certain circumstances blockage could occur. Since blockage of the vent could cause interruption of fuel flow to the engine or fuel tank collapse, the pilot should be alert to the possible hazard irrespective of design precautions.

Airscoop. Ice often forms in and around the airscoop and in the curved passages from the airscoop to the carburetor.

POWERPLANT ICING IN JET AIRCRAFT

Fuel System. Since water easily mixes with jet fuel, the fuel absorbs considerable water when the air humidity is high. Occasionally, enough water is absorbed to create icing of the fuel system when flying in cold air where the fuel temperature is at or below the freezing temperature of water. This problem usually can be eliminated by the application of heat upstream of the fuel filter. The heat can be provided either electrically or by the use of engine bleed air.

Induction System. Ice forms in the induction system any time atmospheric conditions are favorable for formation of structural icing (visible liquid moisture and freezing temperatures). In addition, induction icing can form in clear air when the relative humidity is high and the free-air temperatures generally are 10° C. or lower.

Air Intake Ducts

In flights through clouds which contain supercooled water droplets, air intake duct icing is similar to wing icing. However, the ducts may ice when skies are clear and temperatures are *above* freezing. While taxiing and during takeoff and climb, reduced pressures exist in the intake system. This lowers temperatures to the point at which condensation and/or sublimation take place, resulting in ice formation. The temperature change varies considerably with different types of engines. Therefore, if the free-air temperature is 10° C. or less (especially near the freezing point) and the relative humidity is high, the possibility of induction icing definitely exists.

Ice accumulation can become serious within 2 minutes under these critical atmospheric conditions. In most jet aircraft, an airspeed of approximately 250 knots or greater is necessary to help minimize the situation. At airspeeds of 250 knots and above, air is rammed into the intake system rather than sucked into the engine.

Inlet Guide Vanes

Icing occurs when the supercooled water droplets in the atmosphere impinge on the guide vanes and freeze. As a result, blockage of air to the turbine compressor increases with ice buildup. This reduction of air flow to the engine results in a decrease in engine thrust and, eventually, failure of the engine. This condition can be alleviated by surface heating of the inlet components.

Engine Damage. Damage resulting from icing in centrifugal-flow-type turbojet engines is unknown. However, damage because of ice may occur in axial-flow-type turbojet engines. The shedding of large ice accumulations from components ahead of the compressor inlet may cause damage to the engine structure and may cause engine blowout. Small pieces of ice will pass harmlessly through the engine, but a large piece of ice could cause severe damage to the engine. Use of the de-icing provisions by the pilot before such buildup can occur, will preclude such damage. Ice formed in the compressor during outside parking or storage of an aircraft may result in damage if an attempt is made to start the engine before de-icing the compressor blading.

A CHECKLIST FOR COLD WEATHER OPERATIONS

1. Keep your aircraft in a heated hangar if possible.
2. Cover the pitot tube, wings, and engine(s) if the aircraft is left outside.
3. Remove frost formations on the aircraft with de-icer fluids on mops. Remove any snow or ice, but NEVER USE HOT WATER TO REMOVE ICE of any type. It may freeze and produce a condition worse than before.
4. Check compressor blading for icing prior to starting jet engine (s).
5. Check Notices to Airmen (NOTAMS), especially for snow or ice on runways.
6. Check the weather carefully with qualified personnel; ask any pilot who may have just come through.
7. Wear sunglasses if there is glare.
8. Check controls for restriction of movement.
9. Taxi slowly and use brakes with caution.
10. Avoid water and mud puddles on the ramp, taxistrips, and runway.
11. Be alert for icing of jet engine air intake ducts and compressor-inlet screens.
12. Watch for propeller icing if the humidity is high. After runup in fog or rain, check the

wings and empennage for ice in the propeller wash area.

13. Insure that anti-icing and de-icing equipments are in operating condition before taking off.

14. Check carburetor temperature prior to takeoff. If it is near 0° C., use heat to prevent ice formation or to clear the carburetor of ice, but do not use carburetor heat *during* takeoff unless absolutely necessary. In flight, preheat the carburetor to prevent ice formation; do not wait until an icing condition exists.

15. Avoid taking off in slush or snow, if possible.

16. Be alert for snowbanks during takeoff and landing.

17. Use pitot heater when flying in rain, snow, clouds, or known icing zones.

18. In a freezing rain condition, fly in the layer where temperatures are above freezing. There will always be at least one such layer and this is the only safe way to penetrate a freezing rain condition.

19. If icing can't be avoided, choose the altitude and route of least icing. (Glaze is common in cumuliform clouds; rime ice is common in stratiform clouds.)

20. Watch your airspeed because your stalling speed increases as you accumulate ice.

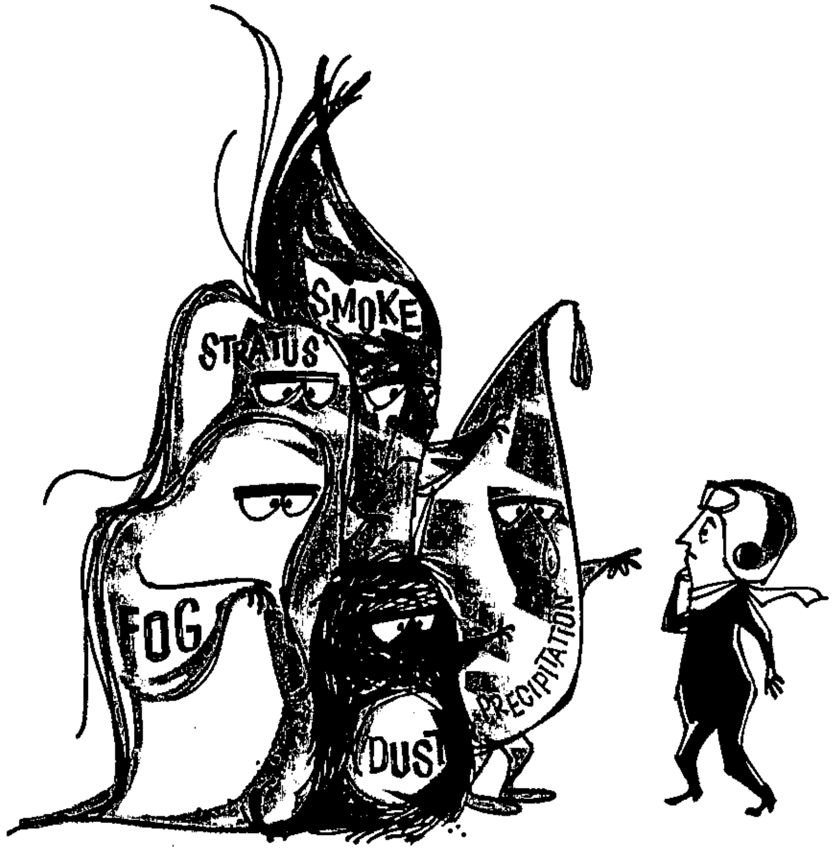
21. Report all in-flight weather hazards.

22. Avoid making steep turns if your aircraft is heavily coated with ice.

23. Use wing de-icers properly; avoid landing with de-icers on because they act similar to spoilers.

24. Before starting your landing approach, if in a conventional aircraft, slowly move the throttle back and forth to make sure that the carburetor butterfly valve is free of ice. Also, extend and retract the landing gear several times.

25. When "iced up," fly in with power.



Chapter 13
COMMON "IFR" PRODUCERS

Statistics show that low ceilings and visibilities contribute toward many aircraft accidents, fatal and nonfatal. Fog and/or low stratus clouds prevent navigation by visual reference more often than any other weather situations. Thus, they have an extremely important effect on aircraft operations, particularly during landing and takeoff. However, fog and low stratus are not the only "IFR producers." Others which are also rather common occurrences are included in this chapter.

Most of the aircraft accidents caused by low ceilings and visibilities involve pilots who are not instrument qualified. These pilots attempt to land, takeoff, or continue flight by visual reference when it is not possible to do so. Pilots who are not IFR qualified (that is, those who do not have instrument ratings) should avoid flying in weather conditions which require operations under Instrument Flight Rules (IFR). They endanger not only their own but the lives of others operating under IFR, and people on the ground. Furthermore, VFR pilots who continue to fly when weather conditions do not permit VFR flight are in violation of the Federal Aviation Regulations and are subject to punitive action.

The percentage of hours when the ceiling is

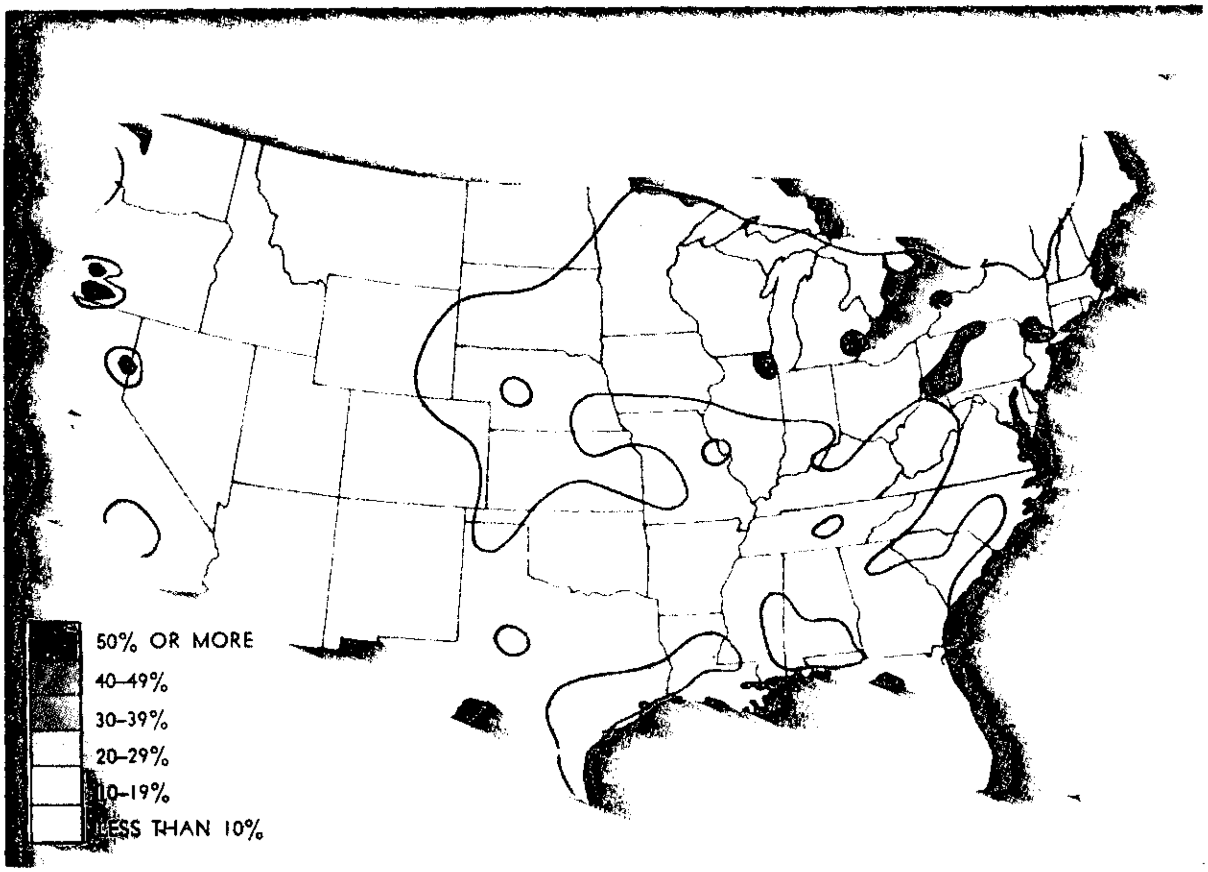


FIGURE 108. Percentage of hours in spring when the ceiling is below 1,000 feet and the visibility is less than 3 miles.

below 1,000 feet and the visibility is less than 3 miles in the contiguous United States is given for the four seasons in figures 108 through 111. Figure 112 shows the maximum percentage of hours that this condition has been observed during any one month during the winter season.

Visual and Instrument Flight Rules are established on the basis of observed ceiling and visibility. It will be helpful at this time to know exactly what is meant by these meteorological terms.

DEFINITION OF CEILING AND VISIBILITY

Ceiling is defined in Federal Aviation Regulations, Part 1 as the height above the earth's surface of the lowest layer of clouds or obscuring phenomena that is reported as "broken," "overcast," or "obscuration," and not classified as "thin" or "partial."

Visibility is defined generally as the greatest distance from which prominent objects can be seen and identified by unaided, normal eyes. "Prevailing visibility," the surface visibility observed at most weather stations, is defined as the greatest horizontal visibility which is equalled or surpassed throughout half of the horizon circle; it need not be a continuous half. This is the visibility which determines whether flights are permissible under VFR or must be conducted under IFR.*

The pilot is concerned also with the visibility he can expect in flight between takeoff and landing. This "flight visibility" is sometimes called "air to air visibility."

* Exceptions to this will be discussed in ch. 15.

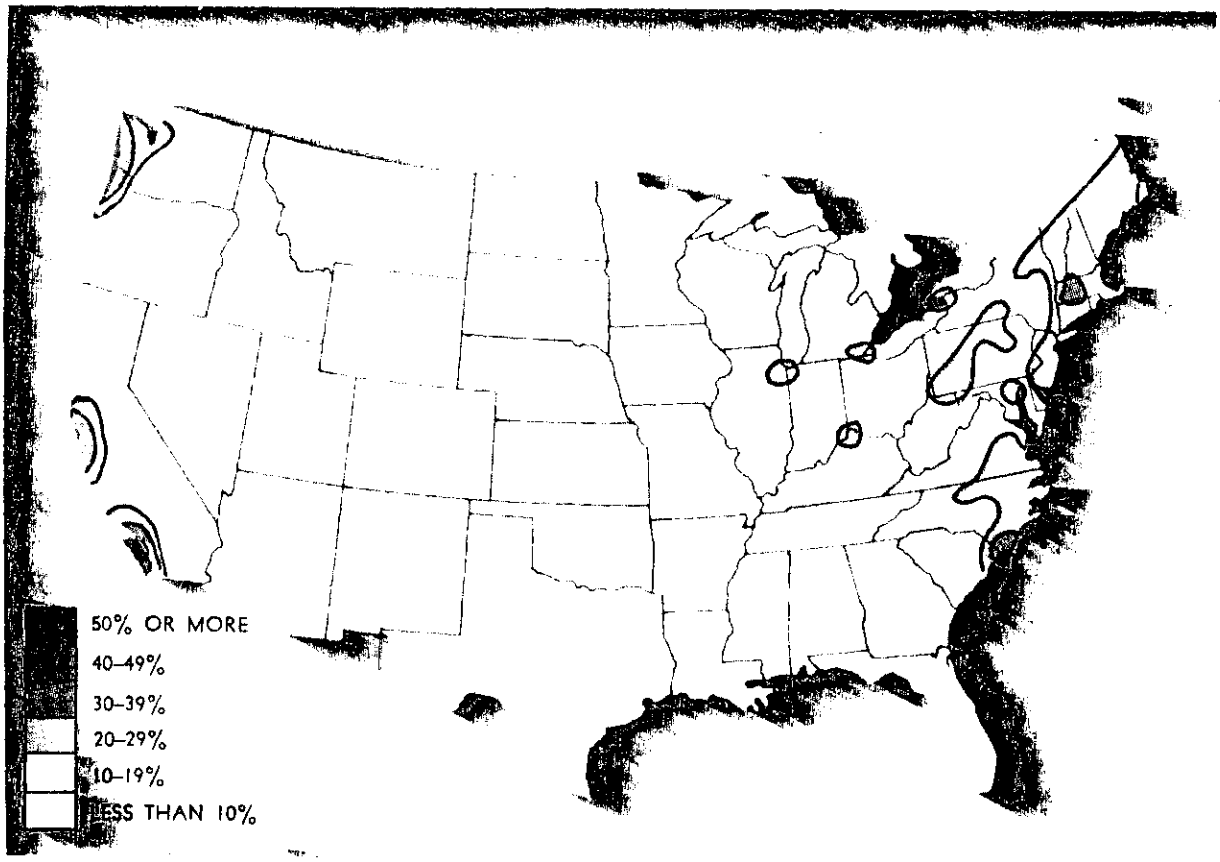


FIGURE 109. Percentage of hours in summer when the ceiling is below 1,000 feet and the visibility is less than 3 miles.

Pilots making instrument approaches for landing are concerned with still another type of visibility. This is the distance from which a pilot on the instrument approach glide path can see landing aids. It is called "approach visibility" or "slant range visibility."

The pilot should bear in mind that the prevailing visibility, flight visibility, and slant range visibility may differ from each other on many occasions. The weather observer can determine only the surface visibility. At most airports, the reported visibility is the prevailing visibility as defined above, although there are other ways of determining surface visibility which are specifically geared to aircraft landing and takeoff operations. These will be discussed in the chapter on weather observations (ch. 15).

The term "visibility" as used throughout this chapter refers to horizontal surface visibility unless it is stated otherwise.

FOG

Fog is one of the most common and persistent weather hazards encountered in aviation. Since it occurs at the surface, it is primarily a hazard during landing and takeoff. Flight visibility above fog is generally good. Fog is the most frequent cause of prevailing visibilities below 3 miles.

Fog is a cloud composed either of water droplets or of ice crystals, depending on the temperature, which lies on the surface of the earth. Since fog normally forms in air which is very stable, there is little or no collision between the droplets or ice crystals, and these particles are extremely small. Therefore, a large number

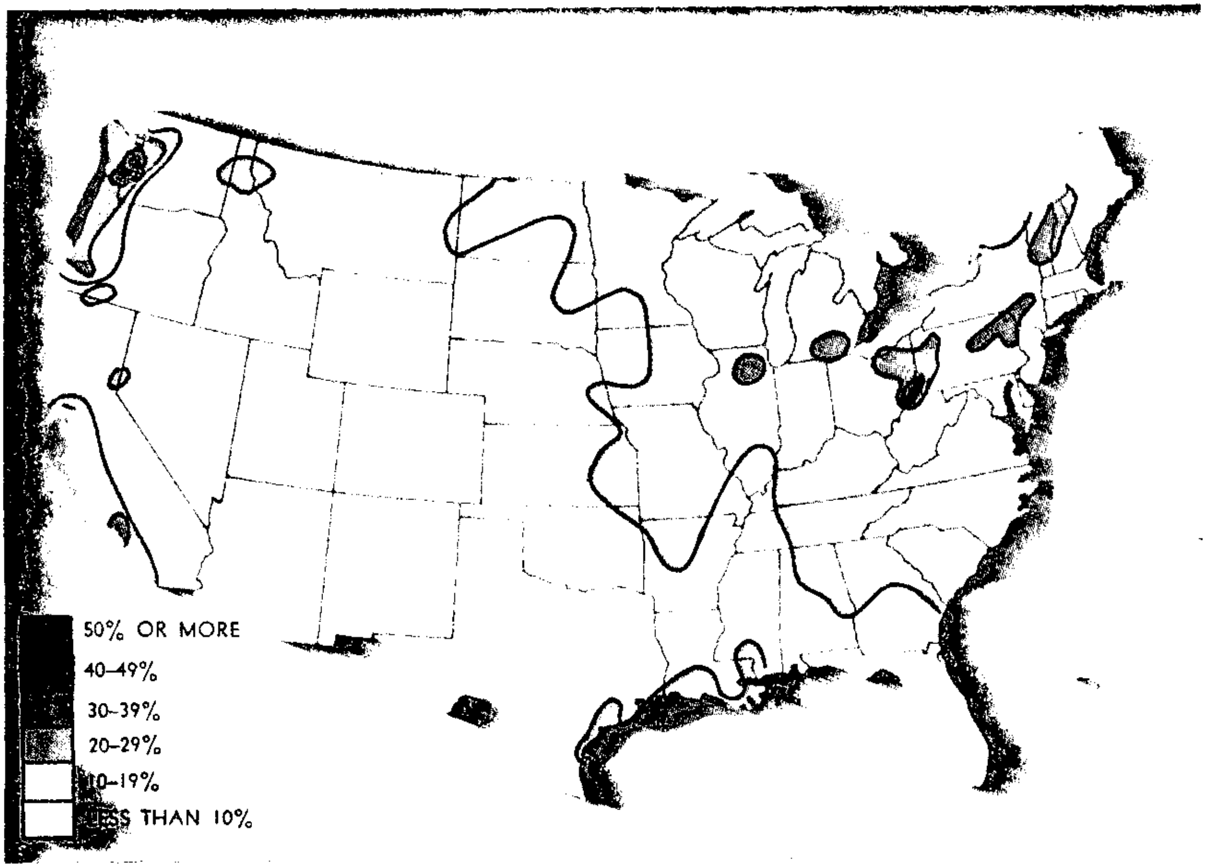


FIGURE 110. Percentage of hours in fall when the ceiling is below 1,000 feet and the visibility is less than 3 miles.

of these suspended particles must be present before the visibility is reduced greatly. However, fog which is dense enough to restrict visibility to a mile or less can form quite rapidly—a gradual thickening does not always occur. An example of this is the sudden increase in fog density that often occurs shortly after sunrise.

Ideal atmospheric conditions for the formation of fog are high relative humidity (small temperature-dew point spread), an abundance of condensation nuclei, light surface wind, and some cooling process to start condensation. Fog is, therefore, more prevalent in coastal areas where moisture is abundant. Even when the relative humidity is less than 100 percent, it is persistent in industrial areas, where products of combustion provide a high concentration of condensation nuclei. Fog occurrences on the whole are more frequent in the colder months, but the season and frequency of occurrence vary from one area to another.

Fog may form (1) by cooling the air to its dew point, or (2) by adding moisture to the air near the ground. Names of various fogs are based upon the way they are formed. In many cases, more than one process is operative at the same time.

RADIATION FOG

Since it forms as a result of radiational cooling of the ground on clear, calm nights, this type of fog is also widely known as "ground fog." The ground cools the air in contact with it to the dew point temperature. Radiation fog is restricted to land areas because water areas do not have much daily variation in temperature. It forms almost exclusively at night or in the early morning and usually disappears within a few hours after sunrise. Ground fog favors flat land areas.

Light wind up to about 5 knots produces a

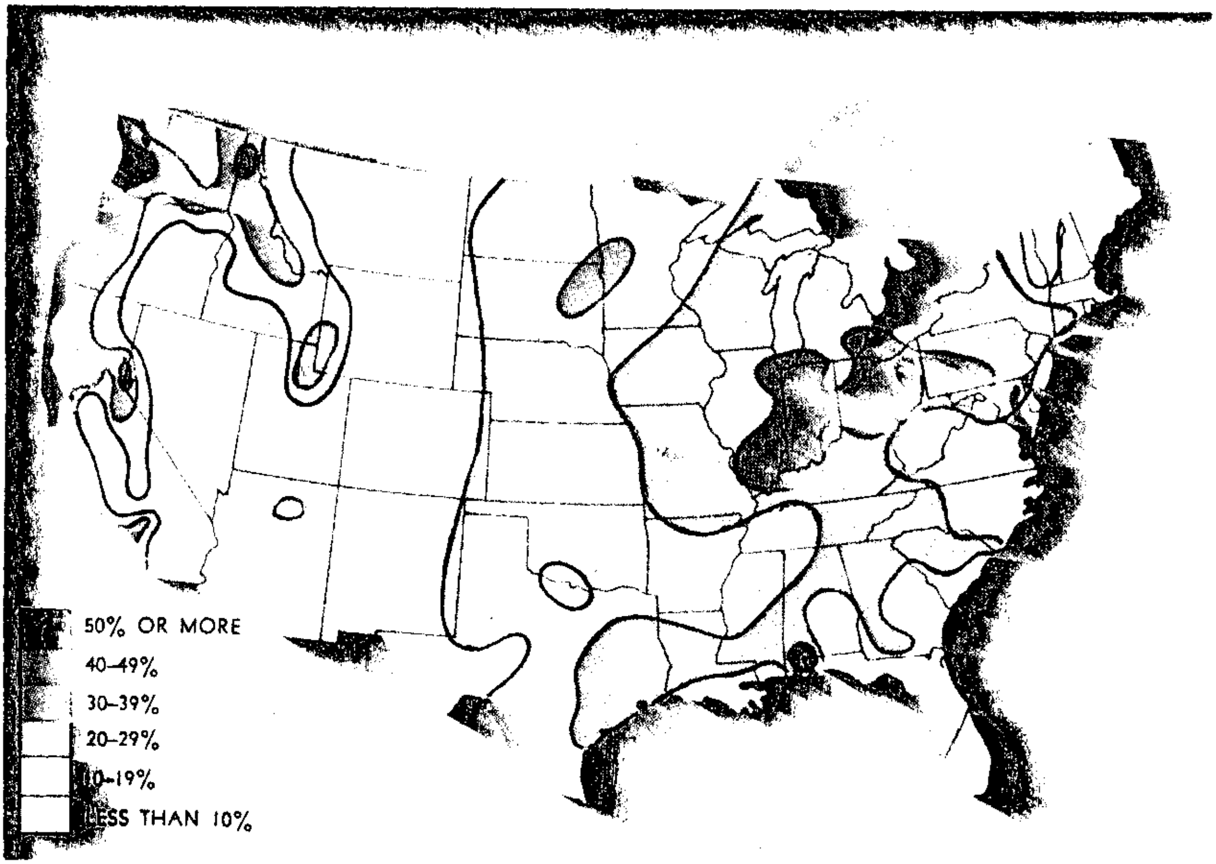


FIGURE 111. Percentage of hours in winter when the ceiling is below 1,000 feet and the visibility is less than 3 miles.

slight mixing of the air, which tends to deepen the fog by spreading the cooling through a deeper layer. Radiation fog usually is very shallow where there is no wind flow. Figure 113 illustrates a ground fog condition.

ADVECTION FOG

This type of fog forms when moist air moves over colder ground or water. Very common along coastal areas, it is often called "sea fog" when occurring at sea. It also can form concurrently with the production of radiation fog.

Advection fog deepens as the wind speed increases up to about 15 knots. Winds much stronger than this lift the fog into a layer of low stratus.

The west coast of the United States is quite vulnerable to advection fog (see fig. 114). This frequently occurring fog forms offshore, largely as a result of very cold water from the ocean depths rising to the water surface, and it is carried inland by the wind.

Water areas in northern latitudes have frequent sea fogs in summer. These water areas do not change very much in temperature from season to season, but moist tropical air moves farther north in summer. Fog forms as a result of cooling of the tropical air from below.

Advection fog over the southeastern United States and along the Gulf Coast (fig. 115) results from moist tropical air moving over cold ground. It is, therefore, more frequent in winter than summer.

UPSLOPE FOG

This fog forms as a result of moist, stable air being cooled by forced ascension up a sloping land surface. An upslope wind is necessary not only for its formation but also for its continued existence. If the wind becomes strong, the fog lifts and becomes low stratus clouds.

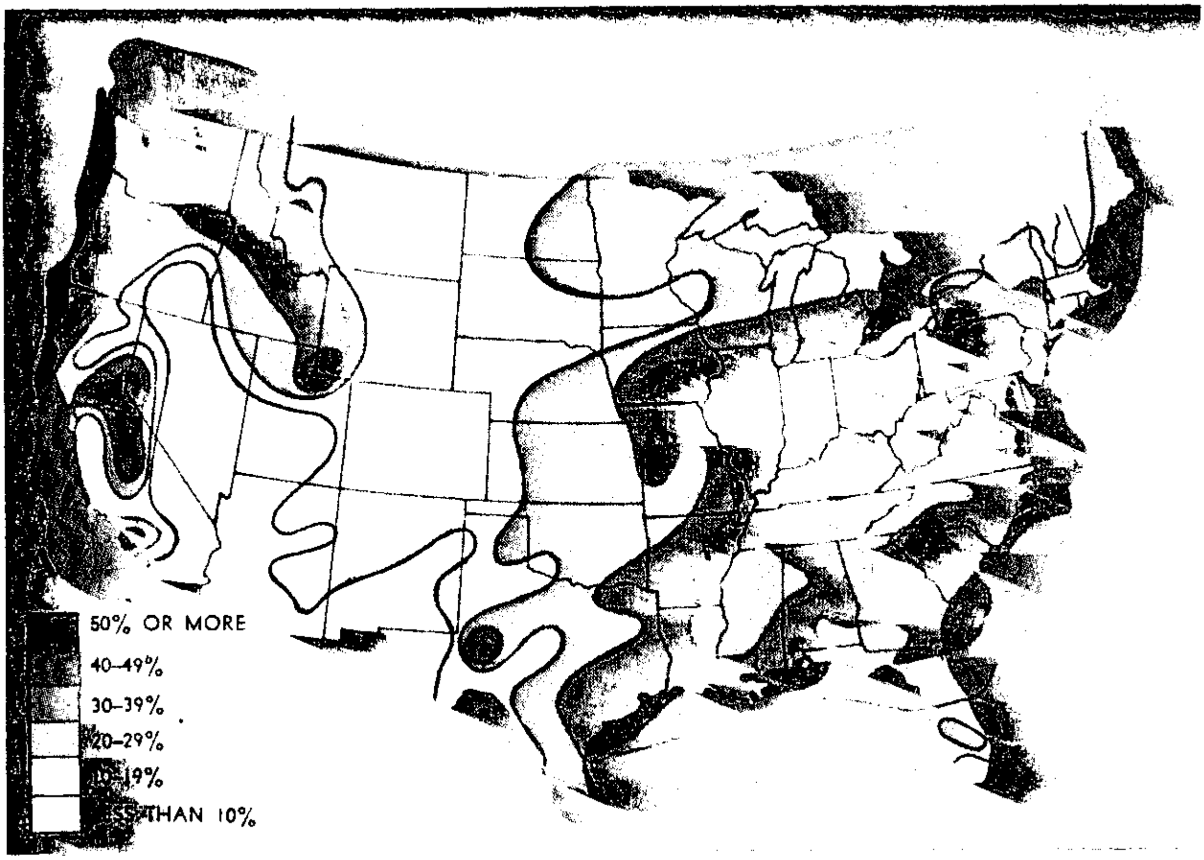


FIGURE 112. Maximum percentage of hours during any one month in winter when the ceiling is 1,000 feet or less and the visibility is less than 3 miles.

Upslope fog is common over the eastern slopes of the Rockies and somewhat less frequent east of the Appalachians.

STEAM FOG

The movement of cold air over much warmer water causes intense evaporation. This usually adds enough water vapor to the cold air to saturate it, and fog forms. Steam fog rises from the water surface like smoke, and it is sometimes referred to as "sea smoke."

Since steam fog, unlike advection fog, forms over a warm surface, heating from below tends to make the air unstable. Therefore, turbulence and icing are often encountered in this type of fog.

Steam fog sometimes is observed over rivers and lakes in the middle latitudes in autumn—the water surfaces cool much more slowly than land and are still relatively quite warm compared to an invading cold air mass. It occurs frequently in the winter over open bodies of water in polar regions.

PRECIPITATION-INDUCED FOG

This fog is caused by the addition of moisture to the air through evaporation of rain or drizzle. Evaporation can occur both when the precipitation is falling through the air and after it reaches the ground. Most frequently associated with warm fronts, this fog may form sometimes with cold and stationary fronts. Other factors being favorable, it can occur with nonfrontal as well as frontal precipitation. When associated with a front, precipitation-induced fog usually forms rapidly, covering a large area, especially when it accompanies warm-frontal precipitation.

ICE FOG

"Ice fog" forms in moist air during extremely

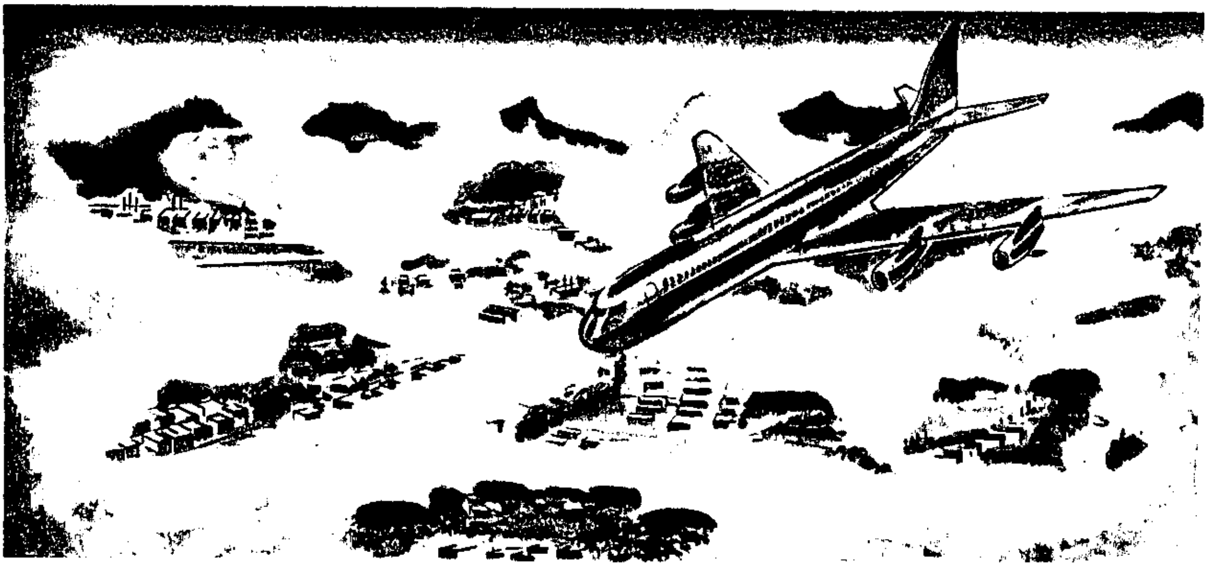


FIGURE 113. Ground fog as seen from the air.

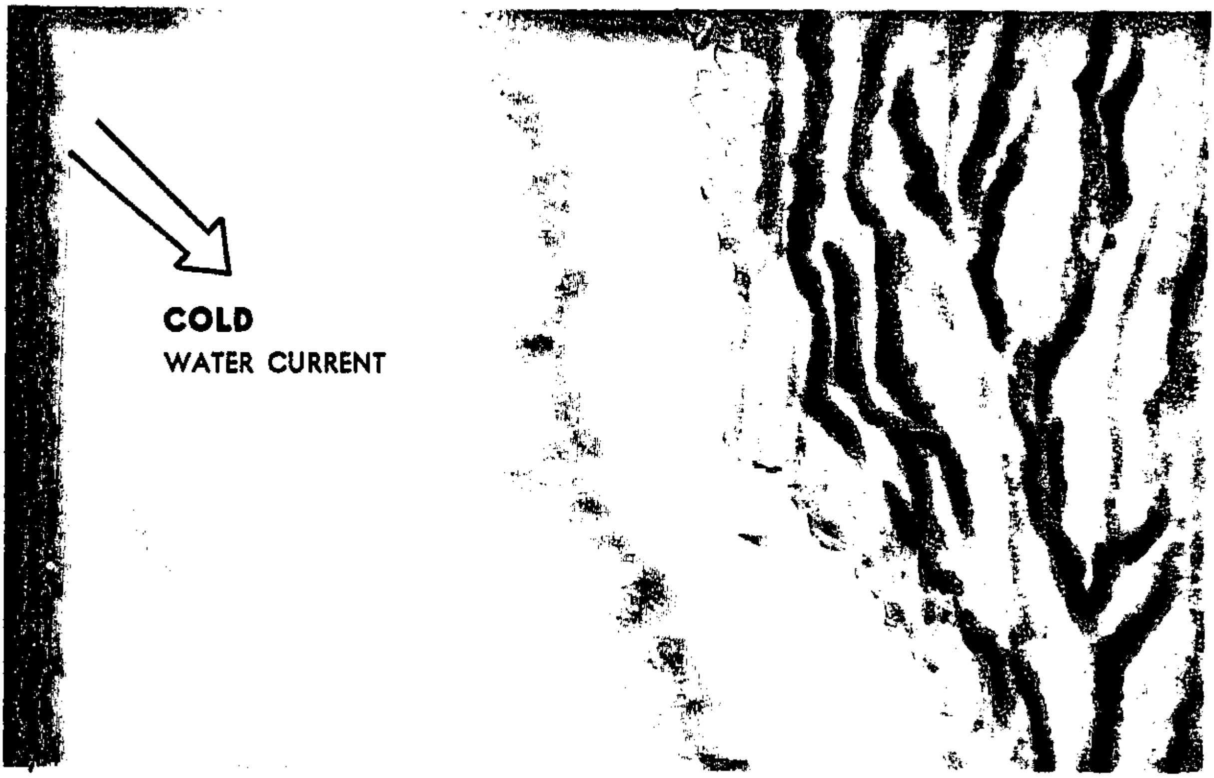


FIGURE 114. Advection fog in California.

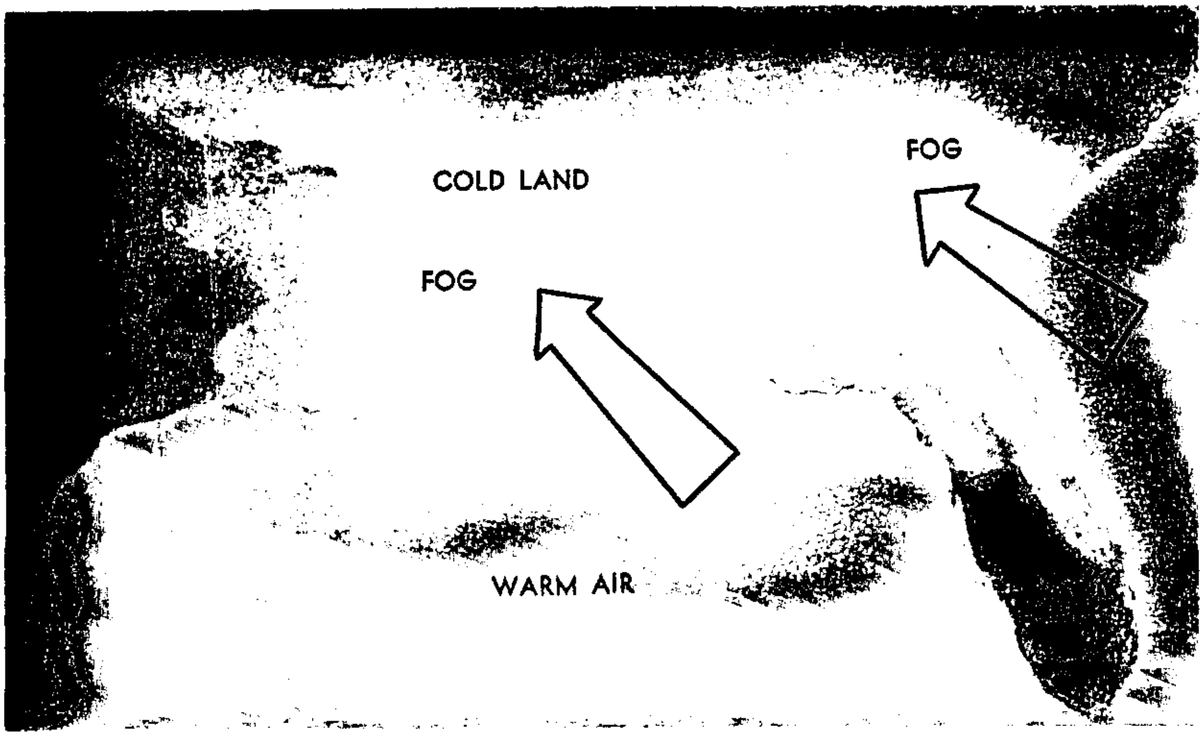


FIGURE 115. Advection fog over the southeastern United States and the Gulf Coast.

cold, calm conditions. The tiny ice crystals composing it are often called needles or spicules, and when the sun shines on these suspended particles, very bright reflections or shimmering lights result. Effective visibility is dependent largely upon whether or not one is looking toward the sun. Ice fog is not uncommon as far south as the northern Plains States but occurs mostly in the Arctic.

Sudden ice fog formation over an operationally significant area may be triggered by local sources of water vapor, condensation nuclei, or turbulence, such as might be induced by aircraft, automobiles, factories, laundries, animal herds, etc. When the wind is very light and the temperature is about —30° F. or lower, ice fog often forms almost instantaneously in the exhaust gases of automobiles and aircraft. It sometimes lasts for days, but its duration may be as little as a few minutes.

LOW STRATUS CLOUDS

Stratus clouds, like fog, are composed of extremely small water droplets or ice crystals suspended in the air. The main distinction from fog is that stratus is a layer above the ground and does not reduce the horizontal visibility at the surface below it. An observer on a mountain enveloped in the layer would call it fog, while one farther down the slope would call it stratus.

Stratus and fog frequently exist together (illustrated in fig. 116). A cross-section of such a condition might appear as a layer of suspended water droplets extending from the ground to some height—perhaps several hundred feet or more—suddenly becoming denser as the cloud base is entered. Because of the reduction in upward visibility, the observer on the ground recognizes the condition as stratus. There is no firm distinction between stratus and fog other than the height at which it is

FIGURE 116. Fog and low stratus.

found. In the vertical, it is a sudden transition from a less dense fog to a denser fog that gives the effect of a cloud.

Both slant range and flight visibility may approach zero in stratus clouds, depending on the density of the cloud.

HAZE AND SMOKE

Haze occurs when the lower layers of the atmosphere are stable and small particles of dust or other impurities, except smoke, are suspended in the air. Much of the reduction in visibility near large cities is due to smoke from manufacturing plants or other industrial activities. When haze and smoke occur together with fog and stratus, the combination is called "smog." This results in very poor visibility.

Haze occasionally extends to about 15,000 feet above the earth's surface. A haze layer often has a well defined top, and horizontal visibility above it is good. Air to ground visibility is poor, however, even from above the haze layer. Visibility within the haze varies greatly, depending largely on whether the pilot is facing into or away from the sun. When haze is present, it is often difficult to land an aircraft into the sun.

Smoke restricts visibility in a manner similar to haze, although smoke from forest fires frequently is concentrated in layers aloft with good horizontal visibility beneath the smoke.

BLOWING OBSTRUCTIONS TO VISION

Blowing dust is observed in relatively dry areas when the air is unstable and the wind is strong. The wind and vertical currents may spread the dust over wide areas, lifting it to great heights (often to 15,000 feet). Blowing dust reduces surface, flight, and slant-range visibilities to very low values.

Sand storms are more local than dust storms, and the sand is seldom lifted above 50 feet. However, visibilities within it are near zero. *Blowing sand* is found in desert regions where loose sand is lifted by a strong wind.

Blowing snow can be as troublesome to a pilot as ground fog. To distinguish it from drifting snow, weathermen have specified that snow must be lifted by the wind to a height of 6 feet or more before being classified as blowing snow. Generally, drifting snow becomes blowing snow when the wind is strong.

PRECIPITATION

Rain, drizzle, and snow are the forms of precipitation which most commonly present a ceiling and/or a visibility problem.

Drizzle and snow usually restrict visibility to a greater degree than rain. Drizzle falls in stable air and, therefore, is usually accompanied by fog, haze, or smoke, frequently resulting in poor visibility. Visibility is oftentimes reduced to zero in heavy snowfall.

Rain seldom reduces surface visibility below 1 mile, the exception being in brief, heavy showers. But rain does present the pilot with a visibility problem when he is flying through it. When rain streams over the aircraft windshield, freezes on it, or "fogs" over the inside surface, the pilot's visibility to the outside is greatly reduced.

OBSCURED SKY

When the sky or clouds are partially or totally hidden from an observer on the ground, the sky is termed "obscured." The precipitation, smoke, haze, fog, or other visibility restricting condition creating the obscuration, in this situation, extends upward from the surface.

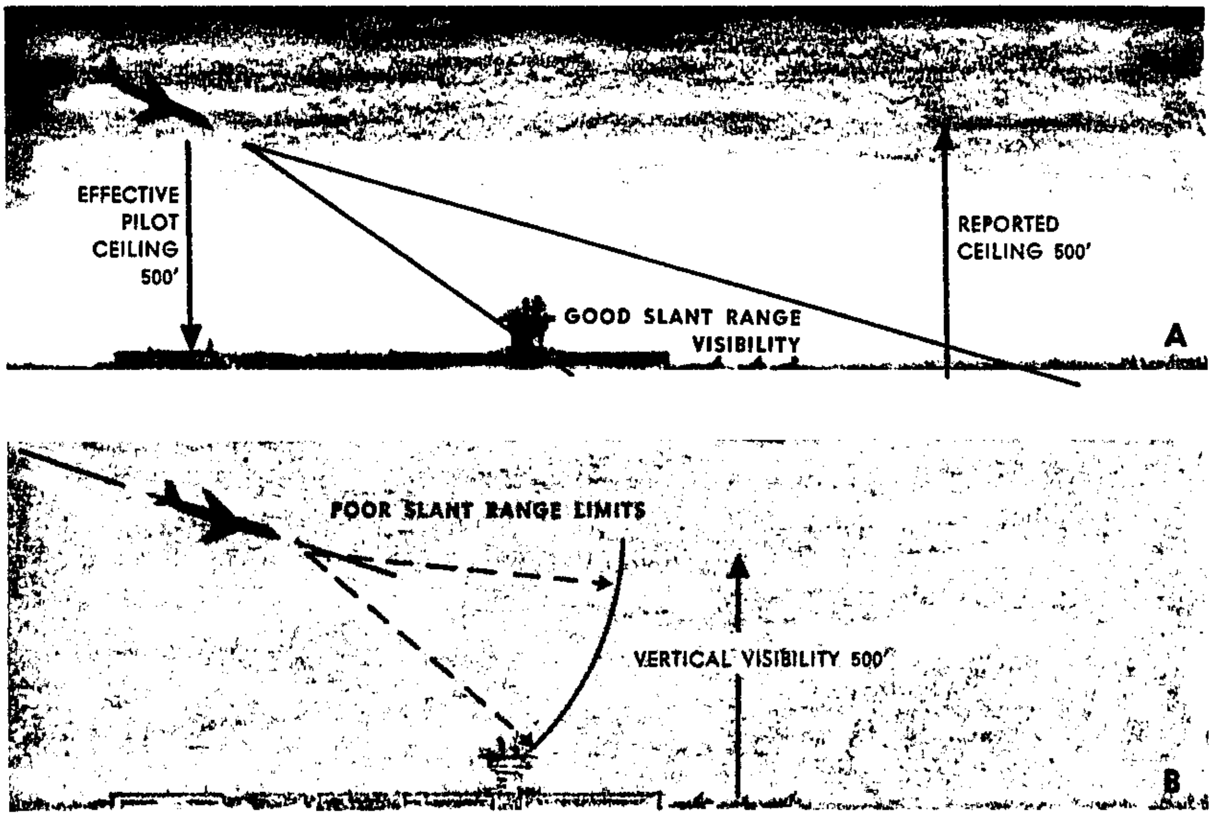


FIGURE 117. Difference between an obscuration ceiling and a ceiling with no restriction to visibility.

TOTAL OBSCURATION

If the sky and clouds are totally hidden, the reported *ceiling* is the *vertical visibility* from the ground. When, for example, the sky is totally hidden by smoke, but the ground observer can see upward for 600 feet, he would report an obscuration ceiling of 600 feet. The exact way this would appear in an Aviation Weather Report will be covered in the chapter on weather observations.

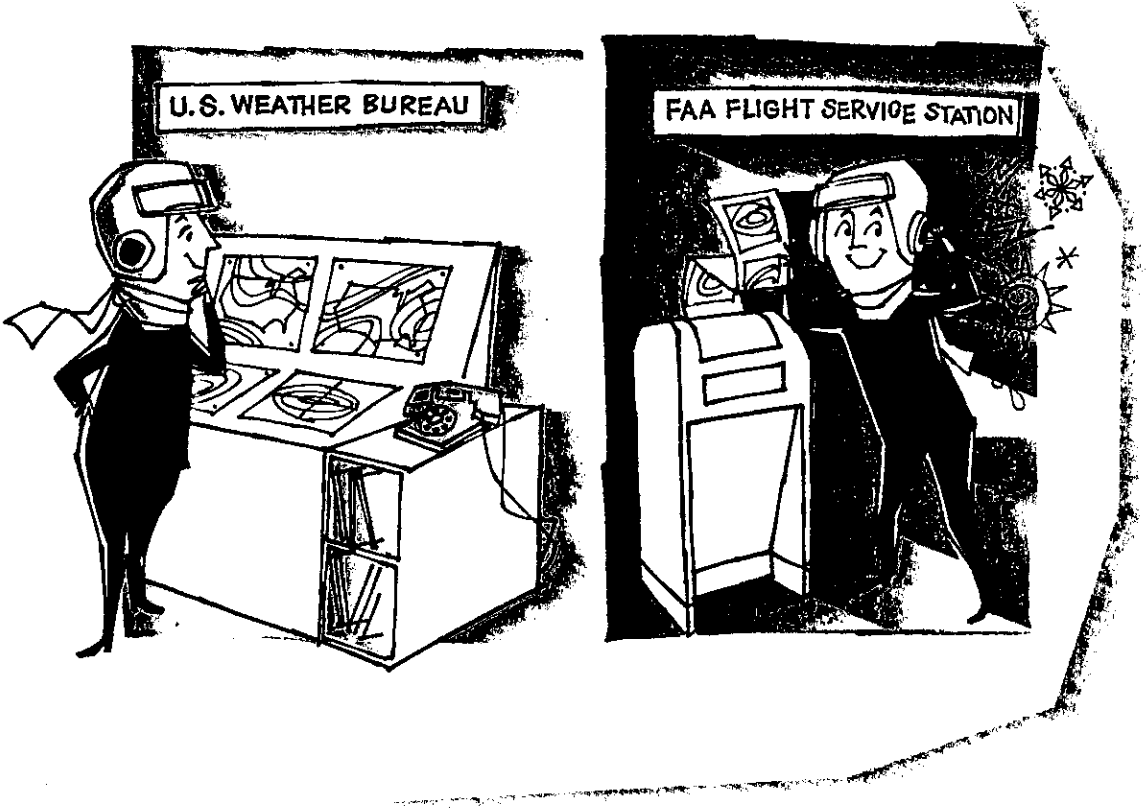
The main point to be learned here is that the obscuration ceiling of 600 feet in the foregoing example is very different from a cloud ceiling of 600 feet. With a low cloud ceiling, the pilot normally can expect to see the ground and the runway once he descends to a level below the cloud base. The visibility must be fairly good —otherwise the ground observer would be unable to distinguish the base of the cloud.

In the case of the obscuration ceiling, however, the visibility condition hiding the sky and the cloud base reaches to the surface; the pilot normally will not be able to see the runway or approach lights clearly even after penetrating the level of the reported obscuration ceiling. The difference in the two ceilings is illustrated in figure 117. The pilot's greatest concern on his approach for landing is to be able to see the runway or approach lights. In other words, his slant range visibility must be good enough to enable him to see the runway or runway lights a reasonable length of time before the touchdown point is reached.

PARTIAL OBSCURATION

If the ground observer is able to see part of the sky dome or clouds through an obscuring condition, he reports a partial obscuration. In this situation, unlike the case of a total obscuration, vertical visibility is not reported. If clouds are present, their bases and amount are reported.

Partial obscurations also present a slant range visibility problem for the pilot approaching to land but usually to a somewhat lesser degree than the total obscuration.



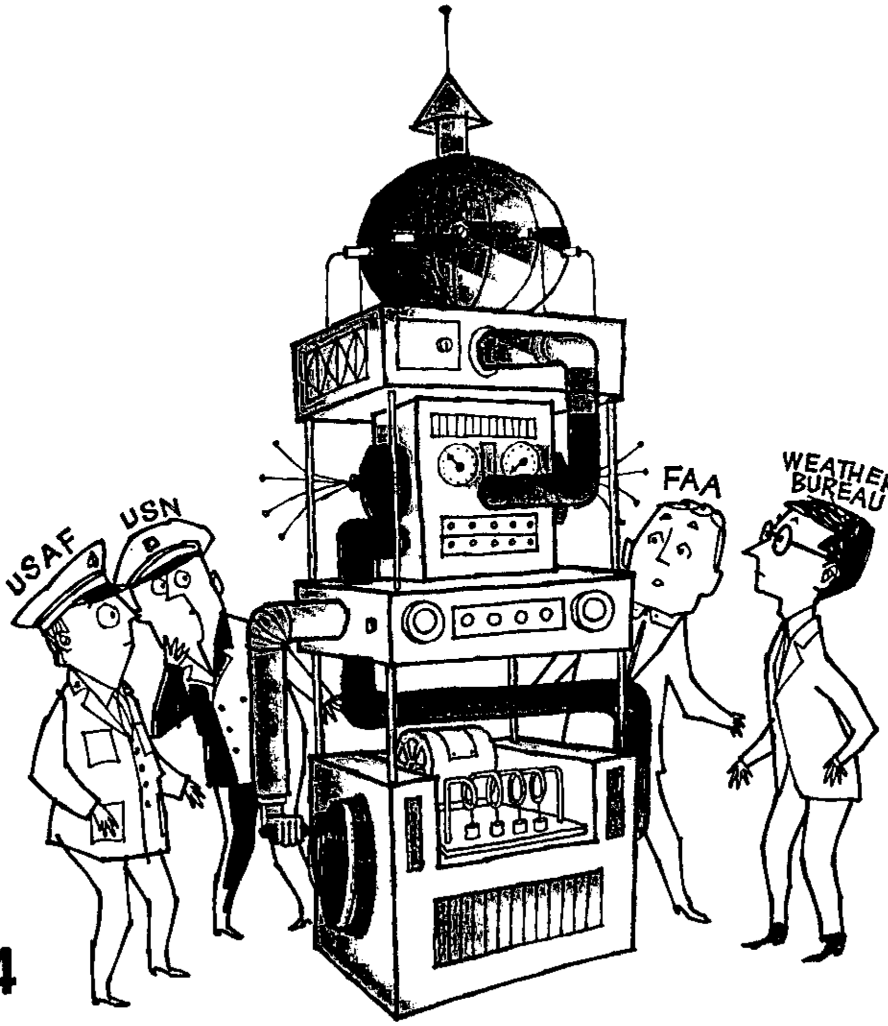
Part TWO

PRESENT AVIATION WEATHER SERVICES

NOTICE TO READERS

Information in Part Two is subject to change without notification, as organizational changes, new services, new procedures, etc. become established. The reader should refer to "Weather Services for Pilots" and other Weather Bureau and FAA publications for up-to-date information.

The examples of all teletypewriter messages in Part Two have similar content to those typically appearing on teletypewriter circuits. Lines in actual teletypewriter messages extend to full page width, if needed, because the time consumed in preparing and transmitting each message must be held to a minimum. The format of some of the examples herein are presented in column width rather than in full page width. The selection in each case was based on which would provide the greater ease of reading.



Chapter 14
THE NATION'S AVIATION WEATHER SYSTEM

Part Two is presented to acquaint the pilot with (1) the weather system which is supporting him, (2) the interpretation of observed and forecast information, (3) the means through which he can receive this information, and (4) the benefit he can derive from it.

This chapter deals with the nation's weather service organization, its functions, and its services to aviation. As the agency responsible for the nation's weather service, the Weather Bureau is the primary organization for providing weather services to pilots. It has counterparts in many foreign countries. To take, collect, and transmit the thousands of observations, to prepare and transmit forecasts, and to provide the briefing services which are now available to pilots would require an organization many times the size of the Weather Bureau. The agency has found it both economical and efficient to obtain the cooperation of other government agencies, military and civil, as well as private individuals and organizations to satisfy the overwhelming weather service requirements of a rapidly expanding aviation community.

The existing aviation weather service of the nation emerged in slow transitional stages from what had been predominantly a public weather service for many years. It did not come into being as a preplanned operation. The requirements for a special type of weather service to meet the increasing needs of aviation were recognized and, until recent years, this special service was provided within the economic framework of the general weather service. In the past few years, there has been a more rapid transition to a service tailored to meet the requirements of aviation. Further improvements are in progress.

Principal United States government agencies which cooperate with the Weather Bureau in carrying out its responsibilities to aviation are the following:

Federal Aviation Agency
Air Force
Navy
National Aeronautics and Space Administration
Coast Guard

Discussions of the four major operational functions of the aviation weather system (observing, analysis and forecasting, distributing, and presenting) will reveal specific roles of these agencies as part of the system. Preceding these discussions are the following statements on the broad relationships between the Weather Bureau and other governmental agencies in serving pilots and other users of aviation weather information.

RELATIONSHIP BETWEEN THE WEATHER BUREAU AND THE FEDERAL AVIATION AGENCY

The Weather Bureau and the Civil Aeronautics Administration (CAA) grew up together in the Department of Commerce and, since CAA became the Federal Aviation Agency, many cooperative arrangements established between the CAA and the Weather Bureau remain in force. In more recent years, such arrangements have extended to new weather activities.

Almost all official hourly weather observations are now made at airports. The Weather Bureau, the FAA, many airlines, and other cooperators share in the overall job. All weather observers meet the qualification standards established by the Weather Bureau.

As air trips grew in length and duration, the need to know weather conditions at faraway places and to have such information as the status of airport landing facilities became increasingly great. In keeping with the times, a long-line teletypewriter network (now known as Service A) was established to carry aviation operational information including weather. The heavy weather traffic, brought about by the large increase in the number of aviation observations together with other needed weather information, soon dominated the circuit time. FAA then established additional teletypewriter circuitry which will be discussed later. Even today, the FAA remains the nation's principal distribution agency for weather information.

To some extent, the FAA had been a direct link between the Weather Bureau and the pilot long before its pilot weather briefing service began several years ago. Weather observations have been available to pilots through FAA for many years, both through scheduled radio broadcasts and through ground facilities. The FAA's more recent pilot weather briefing service became necessary with the spectacular growth of the pilot "fraternity." It became increasingly difficult for every pilot to get the service he needed from the Weather Bureau. Under a cooperative arrangement between the two agencies, the Weather Bureau trains and certificates FAA Flight Service Specialists as briefers of both current and forecast weather information. An improvement in briefing quality within both agencies has been realized through the Weather Bureau's Quality Control Program in which briefers are spot-checked for proficiency in both face-to-face and radio weather presentations.

In addition to close coordination in such activities as planning and research, which takes place at headquarters level, field directors and personnel of local offices of the two agencies maintain a close working relationship. Joint use of the Weather Bureau's radar and joint maintenance of certain types of equipment are among other cooperative arrangements which have been effected.

RELATIONSHIP BETWEEN THE WEATHER BUREAU AND THE MILITARY WEATHER SERVICES

The military weather services and the Weather Bureau cooperate with one another at all levels. It is understandable that the military services have no responsibility for providing a civilian weather service—this is by law the job of the Weather Bureau. Weather services of the Department of Defense, in concentrating their efforts toward satisfying military requirements, directly serve military interests almost exclusively. However, the Weather Bureau and the military weather services exchange information extensively. Weather Bureau processing centers, such as the National Meteorological Center, the Severe Local Storms Forecast Center, and the National Hurricane Center, serve military as well as civilian requirements.

Department of Defense agencies have their own weather organizations because of special requirements which differ from those of civilians. In meeting Armed Forces requirements, weather services within the military agencies use the information furnished by the Weather Bureau, supplementing it as necessary.

Most civilian pilots are not concerned with the facilities of the military weather services since these facilities generally are not available to them except in emergency situations. Although normally available only to military interests, these facilities are part of the nation's aviation weather system and are mentioned in various parts of this manual in order to complete the reader's picture of the major aviation weather activities of our government.

OBSERVING

The term "observations" is used to cover both measured and estimated existing values of weather elements. As advanced equipment is added, "observations" are increasingly becoming "measurements." Observations are made at the ground (surface), from the ground, and aloft.

SURFACE OBSERVATIONS

Surface observations are the most readily obtained. Those for aviation are made by Weather Bureau personnel, the military weather services, Federal Aviation Agency specialists at selected Flight Service Stations (FSS) and tower facilities, and by other cooperators, mostly airlines. Surface observations from Navy and commercial ships at sea further add to the weather picture. Automatic observing stations (see fig. 118) are being added to the network of surface observation sites. All observations made by other organizations are available to the Weather Bureau, and vice versa.

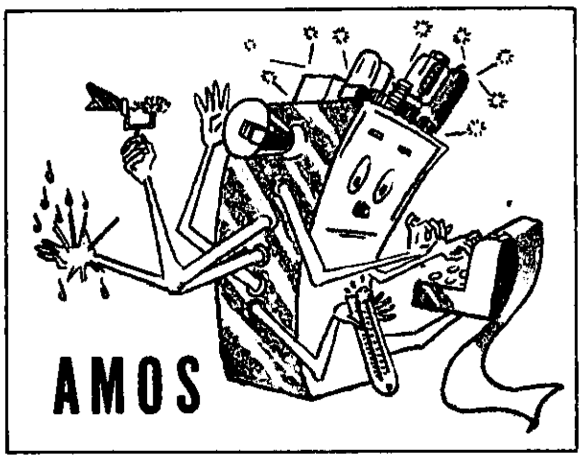


FIGURE 118. The basic components of the automatic weather station.

In addition to these surface observations with an established format, civic minded volunteers in many areas watch for and report storm conditions. Organizations such as utility companies, oil companies, state police, telephone companies, and highway departments also assist.

RADAR OBSERVATIONS

These afford a continuous presentation of significant cloud and precipitation patterns in three dimensions. These observations are made by Weather Bureau and military personnel at many locations over the nation.

RAWINSONDE OBSERVATIONS

Other observations of conditions aloft furnish information on temperature, humidity, pressure, and wind, often to heights above 100,000 feet. These are obtained by sending a balloon aloft with miniature weather observing equipment and radio gear. Personnel of the Weather Bureau make nearly all observations of this type, called rawinsondes. These provide the "raw" data for constant pressure charts (ch. 16) and others, such as the adiabatic chart (ch. 6). The Coast Guard operates a number of stationary weather ships in the eastern North Pacific and western Atlantic Oceans which furnish both surface and rawinsonde observations at scheduled intervals. Most upper-air observing stations make observations of wind alone at intervals between rawinsonde observations.

PILOT BALLOON OBSERVATIONS (PIBALS)

When the balloon (without transmitter attached) is tracked visually, such a sounding is called a Pilot Balloon Observation (PIBAL). About 80 stations in the contiguous United States make PIBALS exclusively, supplementing the network of rawinsonde stations.

METEOROLOGICAL ROCKET SOUNDINGS

Meteorological rocket soundings, operated by the Department of Defense and the National Aeronautics and Space Administration, are now used experimentally at a few locations. These are likely to become increasingly common.

PILOT REPORTS (PIREPS)

Important information for aviation comes from the pilots themselves. PIREPS are often the only source of information relating to such conditions as turbulence, icing, and cloud tops.

AERIAL WEATHER RECONNAISSANCE FLIGHTS

Conducted by the Air Force and Navy, these provide another source of weather data. These flights are made on a scheduled basis along fixed routes over relatively inaccessible land and water areas. Trained weather personnel are aboard every flight.

SATELLITE OBSERVATIONS

In addition to providing photographs of cloud patterns over a large area, the satellites, encircling the earth at altitudes between 400 and 600 miles, furnish radiation measurements which will increase man's knowledge of the atmosphere.

International cooperation in the field of weather began even before the postal service and today there is no area of greater cooperation. Those nations operating weather satellites make information on photographed cloud patterns available to all other nations desiring it. An even much larger volume of weather information obtained through scheduled observations is also shared by nations of the world. For example, Communist China, the Republic of China, and the U.S.S.R. are among the many nations which exchange surface and upper air observations with other nations. (See ch. 15 for a detailed discussion of weather observations.)

ANALYSIS AND FORECASTING (DATA PROCESSING)

Some of the analysis and forecast centers of the Weather Bureau routinely and directly support aviation, while others provide general and other special services. Subsequent paragraphs deal with those processing centers which have a direct input into the aviation weather service.

BASIC ANALYSIS AND FORECASTING CENTERS

The National Meteorological Center. The hub of the nation's weather data processing function is the National Meteorological Center

(NMC) of the Weather Bureau, located near Washington, D.C. This center provides guidance material such as analyses and forecasts (prognoses) of hemispheric wind flow patterns at levels from the surface to about 50,000 feet. These charts are essential in coping with current weather prediction problems. Each field forecaster may interpret NMC products without having to perform identical laborious tasks in preparing detailed forecasts for his area.

NMC receives from all over the Northern Hemisphere about 45,000 weather observations of all types each day. Many of the weather charts distributed by the center are prepared automatically. Electronic data processing equipments are actually capable of plotting limited weather data, analyzing the wind flow pattern, predicting the future pattern, and drawing the analyzed chart and the prediction (prognostic) chart. The capability of automatically transmitting the charts by facsimile is near realization. Other meteorological parameters also are routinely analyzed and predicted by the computer.

Prognostic charts distributed by the Analysis and Forecast Division of NMC generally have verification times less than 2 days in the future. Many of these charts, popularly called simply "progs," are valid 18 hours after the observation time of the data on which they are based. The Extended Forecast Division of NMC prepares and distributes extended-period forecasts and outlooks valid at intervals of 5 to 30 days in the future. These are useful to aviation primarily in operational planning.

In a day's time, NMC prepares a total of 250 weather analysis and prog charts. Of these, 120 are prepared by automatic methods. About 80 percent of these charts are distributed to government and private field installations, each transmission requiring an average of only 12 minutes. The talents of 132 meteorologists and 162 supporting personnel are concentrated in NMC.

Forecast centers, depending upon their functions, refine and supplement NMC products as required. NMC serves other Weather Bureau offices, other civil government agencies, and the military services of the United States; many foreign nations routinely use its products. With the continued rapid growth of aviation over most of the world, similar organizations will hold a place of prominence in any system designed to meet the weather service requirements of pilots and others who are involved in moving air traffic of all categories with safety and efficiency.

FLIGHT ADVISORY WEATHER SERVICE (FAWS)

Unlike NMC which provides a generalized weather service, mostly for other weathermen, the Weather Bureau FAWS centers are staffed with aviation weather specialists who devote their entire efforts toward meeting the requirements of aviation interests. These centers prepare and distribute aviation terminal and area forecasts with the assistance of guidance material from NMC and supplementary advisory material which is supplied by District Meteorological Offices and the special processing centers discussed later in this chapter. FAWS centers are further assisted by weather reports from pilots.

Areas of forecast responsibility of the FAWS centers roughly correspond with the areas of responsibility of the Federal Aviation Agency's Air Route Traffic Control Centers (ARTCC's). Figure 119 shows the location and area of responsibility of each FAWS center as well as the locations of other processing units. The FAWS office in San Francisco prepares and distributes regional forecasts (FN–1) in addition to their area forecasts (regional boundaries are included in fig. 119).

WEATHER BUREAU AIRPORT STATIONS

To most pilots and others associated with aircraft operations, the "Weather Bureau" means the Weather Bureau Airport Station (WBAS). Here is the weatherman whom the pilot talks with face-to-face when he goes to the weather office for a briefing, and the voice the pilot hears when telephoning for weather information. The WBAS is the Weather Bureau's main link between the aviation community and the processing centers. Rarely does the pilot visit processing centers other than FAWS offices.

Many pilots have the mistaken belief that the weatherman in a small WBAS is only a briefer

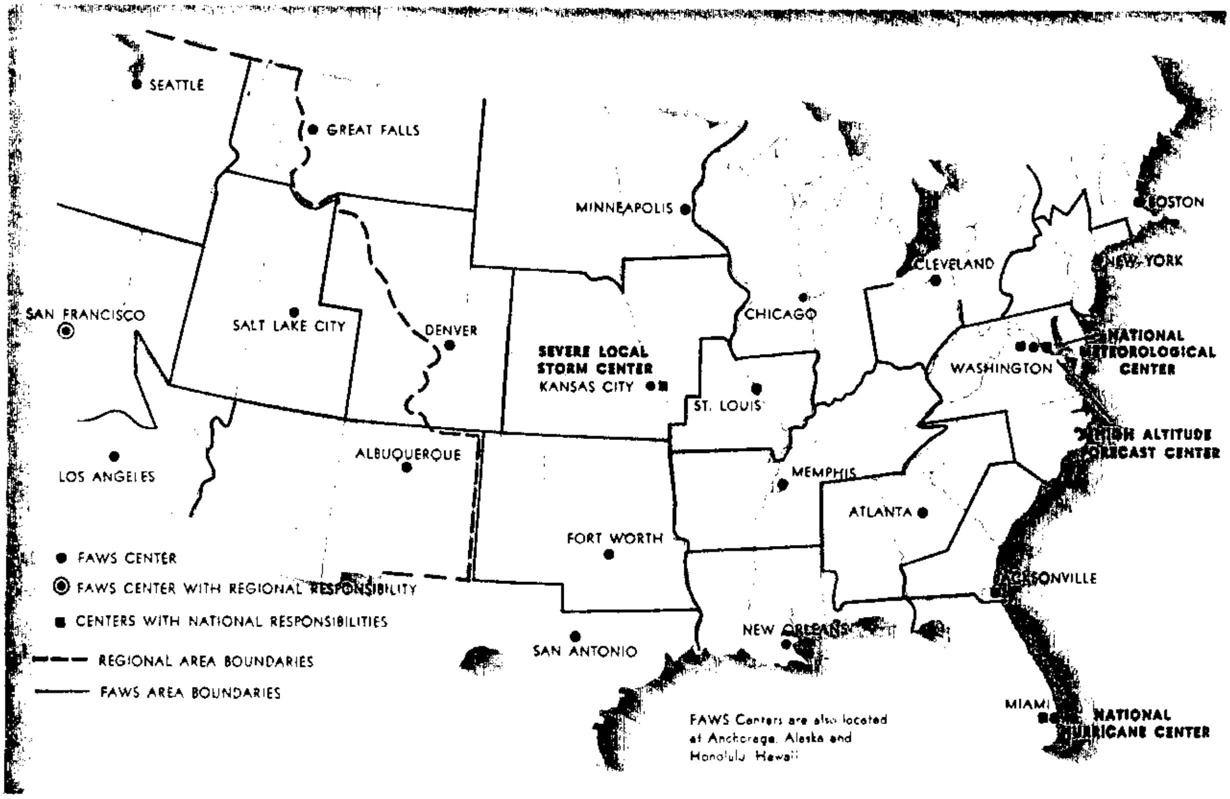


FIGURE 119. Locations of meteorological processing centers and forecast areas.

—an interpreter for pilots of current weather information and of the forecast products of FAWS and other data processing centers. It is true that this is a large part of his job, but, at most locations, aviation weather responsibility is one of many duties of the "observer-briefer." He must do some analysis and forecasting too, on a limited scale. He depends mostly on material received from the larger offices, but he is the one responsible for the information which he gives to pilots and other users. As the principal "retailer" of weather information, the local weatherman has great demands placed upon him.

The local weatherman analyzes the weather in his own area as thoroughly as possible with the aid of data from all of the sources previously mentioned. His analyses often are mental rather than in graphic form because of lack of time to prepare weather charts. It is often necessary for the local weatherman to add refinement to guidance material from the forecast centers because it may not be specific enough for a particular flight problem. And, in rapidly changing weather conditions, he sometimes must deviate from guidance forecasts. Until forecasting becomes more nearly an exact science, predictions are going to go completely "sour" from time to time. When this happens, FAWS is aware of it and issues an amended forecast. However, preparation and distribution of the amended forecast consume time, and the weatherman at the local station is on his own until he receives the amendment. He also is responsible for warning local aviation interests of expected storms or other hazards in the area. The issuance of warnings of hazardous *flying* weather, however, is the responsibility of FAWS. These warnings originate as SIGMETS and ADVISORIES FOR LIGHT AIRCRAFT (see ch. 17).

SPECIAL PROCESSING CENTERS

The Severe Local Storm (SELS) Forecast Center. This facility, located in Kansas City, Mo., issues warnings of severe thunderstorms and their accompanying hazards including tornadoes, funnel clouds aloft, hail at the surface and aloft, areas of extreme turbulence, and surface wind gusts of 50 knots or more. Such warnings are issued as the situation dictates. In addition, a convective outlook is issued early each morning, indicating possible locations of severe local storms during the next 24 hours anywhere in the contiguous United States.

Products of the Weather Bureau's severe storm warning facility are furnished to the military weather services. However, the Air Weather Service of the Air Force provides hazardous weather warnings which are geared specifically to military operations. The two forecast operations are located in the same building, and the Weather Bureau and the Air Force closely coordinate their efforts.

The National Hurricane Center. This special processing center, operated by the Weather Bureau, is located at Miami, Fla. All efforts concerning tropical storms or hurricanes which may affect the southern and eastern United States are supervised and coordinated at this national center.

Reconnaissance aircraft of the Weather Bureau, Air Force, and Navy, carrying weather personnel, locate (if not already pinpointed by radar or by satellite photographs), track, and penetrate hurricanes and other tropical cyclones. These "hurricane hunters" relay information to the National Hurricane Center where it is analyzed and, in conjunction with other information, serves as a basis for forecasts and bulletins. Bulletins and advisories are distributed to Weather Bureau units by teletypewriter and telephone, and to the public and civilian agencies through radio, television, and the press. Issuance of hurricane information to military units is handled through military communications channels by liaison personnel of the Air Force and Navy working in the National Hurricane Center.

The following Weather Bureau offices serve as hurricane subcenters when these storms move into their assigned areas of responsibility:

New Orleans, La.
Washington, D.C.
Boston, Mass.
San Juan, P.R.

The Weather Bureau office in San Francisco, Calif., serves as the hurricane center for tropical cyclones of all intensities in the eastern North Pacific Ocean and along the west coast of the United States. A corresponding service for tropical storms and typhoons in the central and western Pacific is provided through the joint efforts of the Weather Bureau and the military weather services. The Air Force has forecast centers in Japan and Spain which provide such services for military installations in the Far East and the eastern Atlantic-European area, respectively.

(See ch. 21 for information on the nature of tropical cyclones.)

High-Altitude Forecast Centers. The High-Altitude Forecast Center supporting commercial jet aircraft operations in the contiguous United States is a specialized unit of the National Meteorological Center (NMC). Its products, mostly operational forecasts in graphic form, are used more by the airlines than by FAWS and local weather offices. This is understandable because the number of private and business aircraft flying at high tropospheric and stratospheric altitudes is still rather small. Products of this center are received by some FAWS offices, but they also are transmitted directly to the airlines which lease the necessary facsimile (similar to wirephoto) equipment. Six additional High-Altitude Forecast Centers provide highly specialized forecasts of wind, temperature, significant enroute weather, and terminal weather for international flights. One of these is operated in Montreal by the National Meteorological Service of Canada.

All of the High-Altitude Forecast Centers, including the Canadian one, freely exchange forecasts to assure compatibility near boundaries of their respective areas of responsibility. The area served by the seven Centers extends from Japan and the Philippines eastward into Europe, and from the North Pole to the Tropics.

Weather conditions found at high altitudes is the subject of chapter 19.

The National Weather Satellite Center (NWSC). Collocated with NMC, NWSC prepares cloud analyses, called "nephanalyses," for selective facsimile distribution. Weather satellites carry television camera and radiation measuring equipment. Pictures of clouds and storms over a large area are transmitted by command from the satellite to special ground receiving stations which retransmit them to NWSC for processing. The picture usually gives a distorted view because the satellite camera is not pointed directly toward the earth. This distortion is removed in preparing the nephanalyses which is drawn in the same projection as other general features portrayed on NMC charts.

A considerable amount of operationally significant data has been obtained through satellite pictures, especially in the location of tropical cyclones in areas of widely scattered weather observations (ocean and sparsely populated regions). Nephanalyses often reveal cloudiness and fog between reporting stations which would not be known to exist otherwise. This situation occurs most frequently in mountain regions where ridges and slopes may be enshrouded, but reporting stations are too far distant to detect the clouds and/or fog. Nephanalyses also assist an observer situated in a fog or cloud condition to determine its areal extent. Considerable progress has been made in interpreting cloud types and structures, leading to detection of many mountain waves as well as storms. But cloud heights and local weather hazards can only be approximated from satellite information.

Automatic Picture Transmission (APT) from the satellite to relatively inexpensive ground stations is undergoing operational testing. Pictures from the satellite are received as television signals and converted into the proper signals necessary to obtain "hard copy" by facsimile (wirephoto). The entire process, from the time the satellite takes the picture to the receipt of the "hard copy," is completed in less than 5 minutes. Larger forecast offices of the Weather Bureau are equipped to receive these automatic satellite pictures which reveal cloud conditions as far as 2,000 to 3,000 miles away in many cases.

DISTRIBUTING (COMMUNICATING)

Weather information is extremely perishable because of its changeable nature. It loses most of its usefulness if not rapidly distributed to the users. The distributing function is a very large one, including the collection and dissemination of observed ("raw") data and the delivery of products of the analysis and forecasting function. Coded weather data are received in the forecast centers from nearby and far distant places as fast as possible, and analyses and forecasts are widely and rapidly distributed. The coded "raw" data are distributed to Weather Bureau Airport Stations, FAA Flight Service Stations, FAA traffic control facilities, airlines, military weather services, private weather services, and others.

Existing methods for collection and distribution of weather information over long distances are teletypewriter circuits for coded material and facsimile networks for graphic material. Long-line circuitry is employed where available, but radio signals, in conjunction with teletypewriter or facsimile, must be used to collect weather information from and distribute it to most overseas points. Locally, additional distribution methods, such as TelAutograph, Electrowriter, and interphone, often are used to advantage for distances of 20 miles or less.

LONG-LINE AND RADIO DISTRIBUTION

Distribution of weather information in graphic or pictorial form is definitely preferable in many respects to the numbers, letters, contractions of words, and symbols which must be used in relaying weather information by teletypewriter. But the problem is that, without the operation of numerous and very expensive parallel circuits, facsimile networks are presently incapable of handling the volume of weather traffic. The speed of facsimile transmission has doubled in recent years and more improvement is in sight. Future developments may make its use in collecting "raw" weather data more practical. However, the limited capacity of collection and distribution systems was the fundamental reason for adoption of weather codes. These codes permit the furnishing of a large amount of valuable information in a short period of circuit time. They also cause headaches for most pilots until they learn to master the codes.

Teletypewriter Circuits. A one-third increase in capacity of long-line teletypewriter systems has promoted a considerable speedup in the distribution of weather information in recent years. The primary United States civil government systems used for distribution of aviation weather information are Services A, C, and O, operated by the Federal Aviation Agency. These and other long-line networks serving aviation are discussed briefly below.

SERVICE A

The purpose of this system is to collect and distribute aviation operational information, predominantly weather. Traffic consists of:

- Hourly and special observations
- Pilot reports and summaries of pilot reports
- Winds aloft forecasts
- Radar reports and summaries
- 12-hour terminal forecasts
- Aviation area forecasts
- Severe weather forecasts
- In-flight weather advisories (SIGMETS and ADVISORIES FOR LIGHT AIRCRAFT)
- Abbreviated hurricane advisories
- Satellite bulletins
- Regional weather synopses (Far West only)
- Simplified surface analyses and prognoses
- Notices to airmen (NOTAMS)

The Service A system consists of fifteen 100-word-per-minute (w.p.m.) area circuits serving over 450 send-receive stations which enter hourly and special surface weather observations from over 500 locations (fig. 120). Fourteen 100-w.p.m. supplemental circuits, providing essentially the same geographical coverage as the area circuits, serve major users on a receive-only basis (fig. 121). Each of 5 Automatic Data Interchange System (ADIS) centers, connected to an express (857 w.p.m.) circuit, controls the exchange of data between three area and supplemental circuits (fig. 120) and the rest of the system. Also connected to the express circuit are 28 ADIS

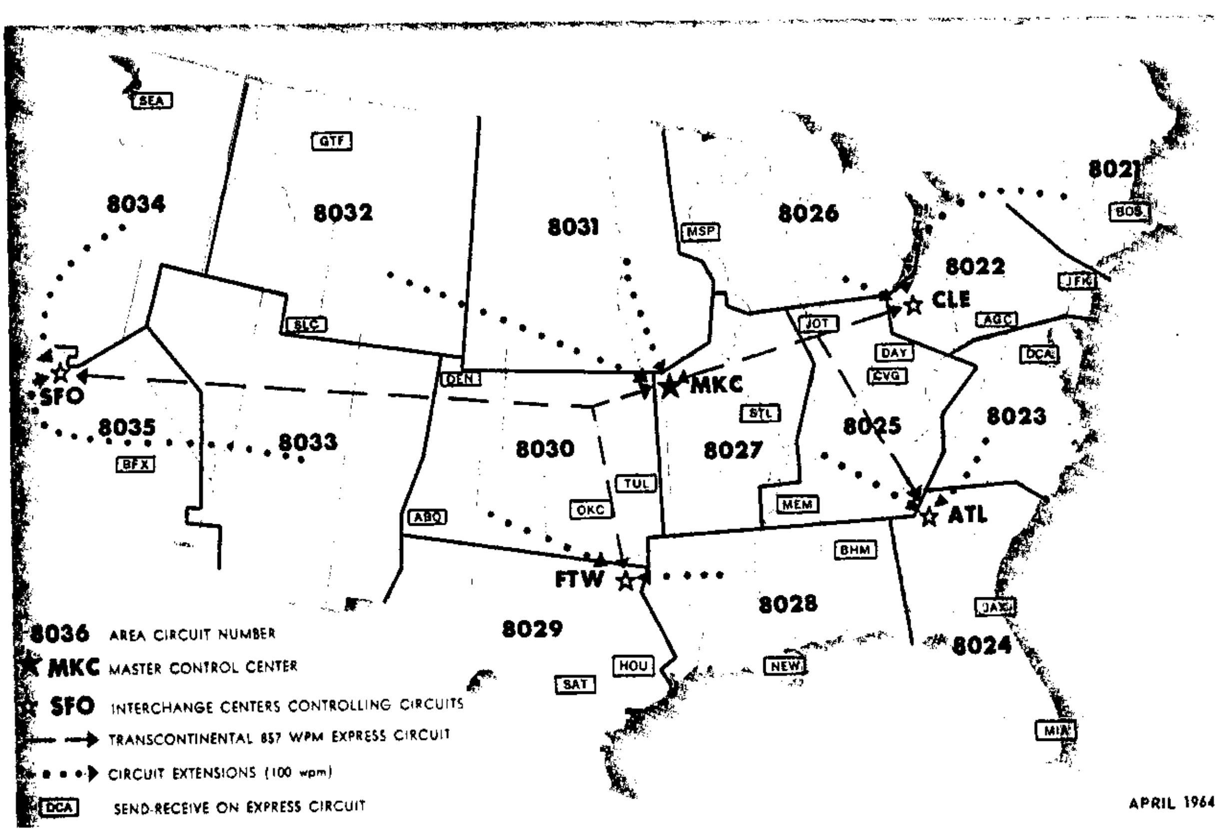


FIGURE 120. Service A primary circuits.

send/receive centers (fig. 120) at locations where there are Weather Bureau FAWS offices or high-activity air terminals. These distribute data from the express circuit to 100-w.p.m. local circuits serving FAWS or WBAS and other subscribers in the immediate vicinity. Some serve also as entry points to the express circuit for FAWS products and weather data from the U.S. Air Force networks and from Canada, Mexico, and the Caribbean.

SERVICE C

This network is used as the primary national distribution system for aviation regional forecasts, and 24-hour terminal forecasts. General service forecasts, upper-air observations, and non-aviation surface observations make up most of the remaining traffic on Service C's network of six circuits (see fig. 122).

SERVICE O

Weather observations, coded analyses and prognoses, and forecasts are interchanged between the United States and foreign nations via the 6 domestic land-line and 13 international radioteletypewriter and cable teletypewriter circuits of this network. The domestic circuits extend to the approximately 100 locations that require overseas information.

RADAR WARNING CIRCUITS (RAWARC)

The three Radar Warning Circuits (fig. 123), operated by the Weather Bureau, provide both sending and receiving capability at about 140 Weather Bureau offices. This network collects radar and hurricane reports in most of the United States east of the Rockies, and collects special upper-air observations and other data essential to forecasting severe weather.

MILITARY NETWORKS

COMET. This Air Force system consists of three teletypewriter networks, each having eight circuits. It is used to collect pilot reports and military weather observations in the contiguous United States and to provide rapid distribution of this information to military users.

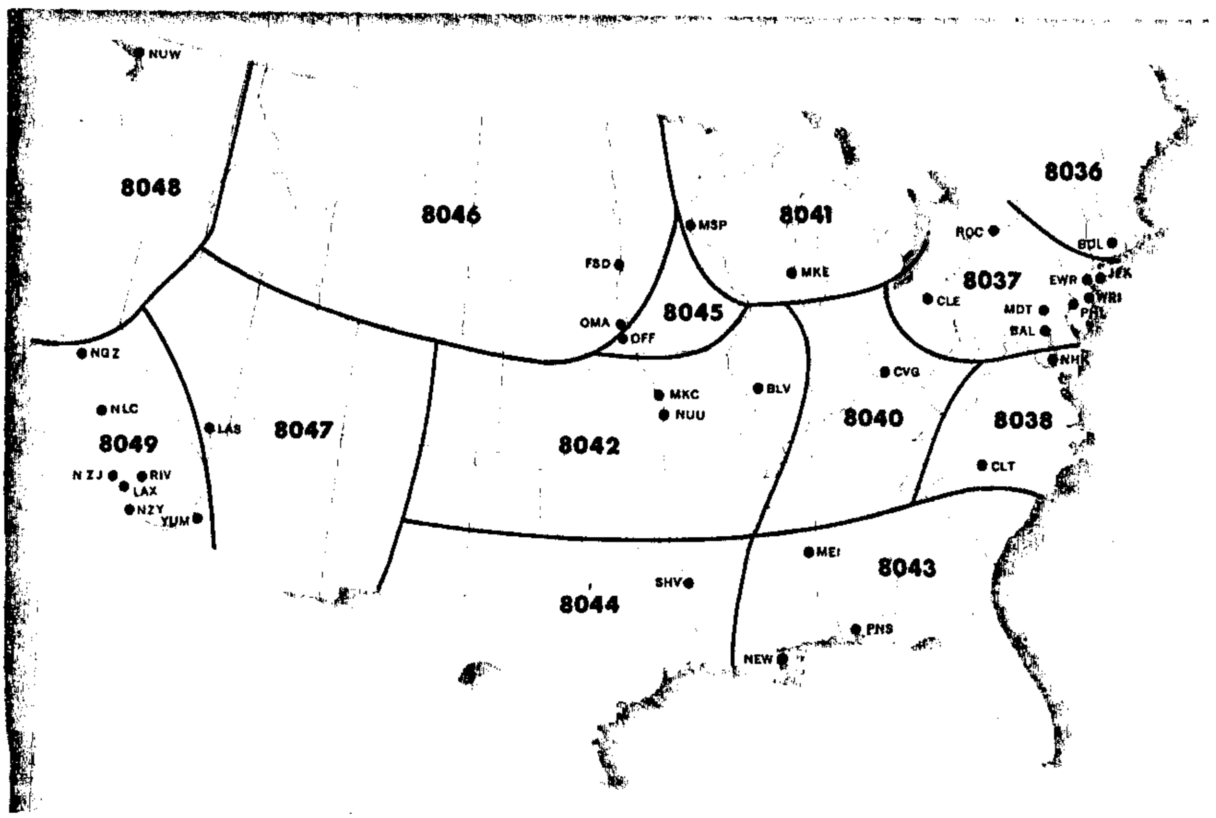


FIGURE 121. Service A supplementary circuits. (April 1964 data.)

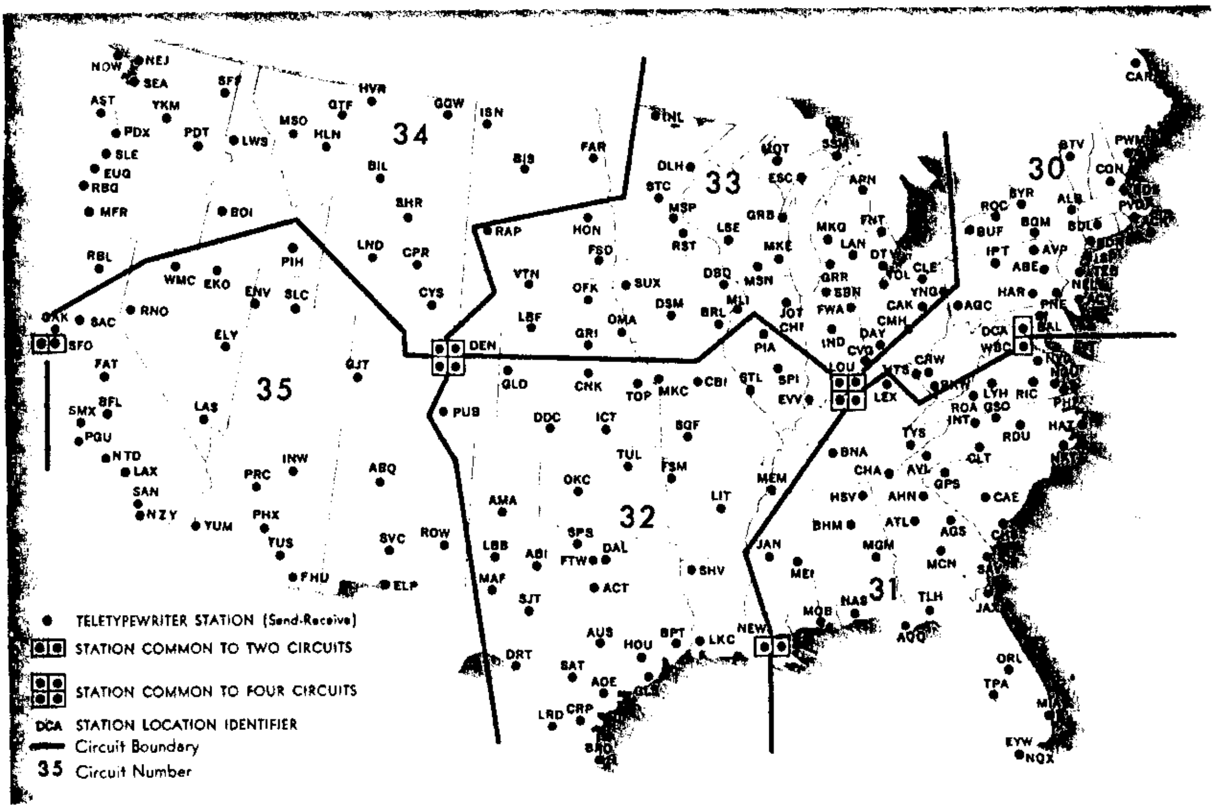


FIGURE 122. Service C circuits.

The three networks are controlled centrally, and information is relayed to and from FAA circuits as needed.

Other Air Force Teletypewriter Networks. Seven regional teletypewriter circuits rapidly collect short-period terminal forecasts and hourly Aviation Weather Reports which are transmitted in a special format for direct input into the SAGE (Semi-Automatic Ground Environment) computers and displays of the Air Defense Command.

The Air Force employs cable for some overseas teletypewriter collection and distribution; otherwise, radioteletypewriters are used.

Navy Radioteletypewriter and "CW" Weather Communications. Responsible for a world weather service, the six weather centrals of the United States Navy collect weather observations from Navy ships at sea either by radioteletypewriter or by International Morse Code (CW) through the worldwide U.S. Naval Communications System. This is not exclusively a weather communications system, and observed weather information is handled as addressed messages to the weather centrals. Area, severe storms, and high seas forecasts are transmitted from the weather centrals to Navy ships as part of the Navy's General Broadcast which also includes other operationally significant information.

Weather Facsimile Networks. As mentioned earlier, facsimile networks are used to distribute analyses and forecasts in graphic form. Special depictions of other types, such as photographs, also can be made through this distribution method.

THE NATIONAL WEATHER FACSIMILE NETWORK

This network, operated by the Weather Bureau, extends to about 360 civil and military weather offices in the contiguous United States (see fig. 124). The equivalent of 130 charts, measuring 12 inches by 18 inches, is distributed by the National Weather Facsimile Network each day. The National Meteorological Center (NMC) originates all transmissions except for

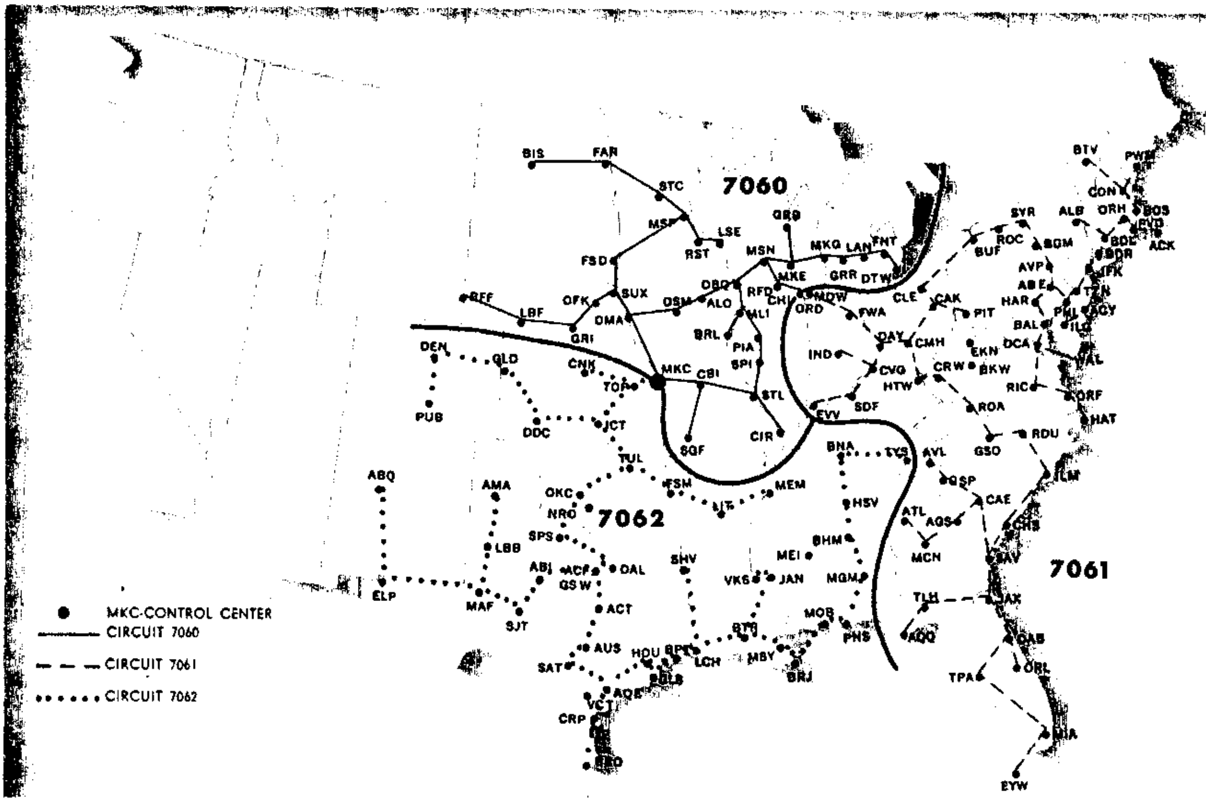


FIGURE 123. Radar warning circuits (RAWARC).

an average of 9 per day made by the Severe Local Storms Forecast Center.

THE HIGH-ALTITUDE FACSIMILE NETWORK

The products distributed over this network are used principally in support of domestic and international commercial jet aircraft operations. The larger airlines lease receiving equipment in order to obtain directly the operational charts transmitted by the High Altitude Forecast Centers. This Weather Bureau-operated network extends to 60 air terminals, with connections at some FAWS offices and military weather stations. Forecasts, distributed in graphic form, are for altitudes between approximately 18,000 and 45,000 feet. The products of all seven High Altitude Forecast Centers placed together cover about two-thirds of the Northern Hemisphere. Long-line circuitry collects and distributes all material within the contiguous United States, and send-receive radiofacsimile systems provide links with foreign nations and Weather Bureau High Altitude Forecast Centers at San Juan, Honolulu, and Anchorage.

THE AIR FORCE STRATEGIC FACSIMILE NETWORK

This network, extending to about 80 military locations, delivers graphic weather products which are oriented chiefly to military operations. Radiofacsimile is used where land-lines or cable are unavailable.

THE NAVY WEATHER FACSIMILE SERVICE

The six Fleet Weather Centrals of the United States Navy, each office with similar responsibilities, individually distribute weather analyses and forecasts for their respective areas of responsibility to smaller fleet weather facilities and to Navy ships at sea via separate all-weather radiofacsimile systems. These individual radiofacsimile systems eventually will become a part of the Navy's computorized worldwide combined all-weather facsimile and teletypewriter system. This computorized system already links Fleet Weather Centrals at Washington, D.C.; Monterey, Calif.; Pearl Harbor, Hawaii; and Guam.

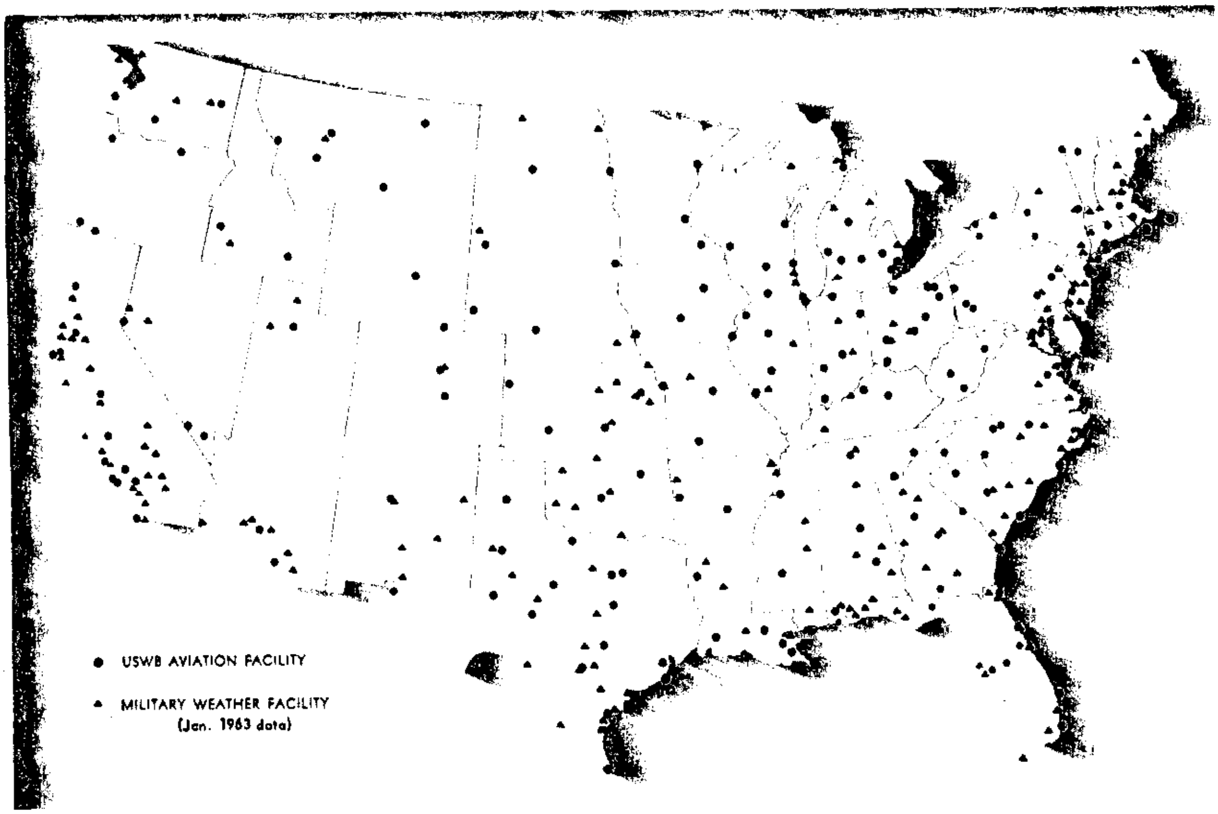


FIGURE 124. The national weather facsimile network.

LOCAL DISTRIBUTION

The weather station is not the only place on an airport requiring a continual flow of fresh weather information. While the number and types of installations on a particular airport depend upon many factors, weather information on a typical large airport is required by airline dispatch offices and operational units of the Federal Aviation Agency, such as the Flight Service Station, the Air Route Traffic Control Center, and airport traffic control facilities. Also, fixed-base operators servicing a large number of General Aviation aircraft usually have some direct link with the weather office, or have a receive-only connection to the Service A teletypewriter circuit. In some cases, a connection to the long-line weather distribution system satisfies the requirements of operational units. However, not only are connections expensive, but also the long-line system carries much more information than is needed in most cases. Flight Service Stations and airline dispatch offices have such connections (some dispatch offices have facsimile connections too), but traffic control units are concerned mostly with weather conditions in the immediate vicinity of, or within 50 miles of the airport. They use regular forecasts for planning purposes but are more concerned with conditions at the present and within the next hour. Such operational units usually have a less costly direct link with the weather office in order to obtain new weather information without delay. Air Route Traffic Control Centers, airline dispatch offices, and Flight Service Stations routinely need regular forecasts and frequently require specific forecasts in connection with individual flight problems.

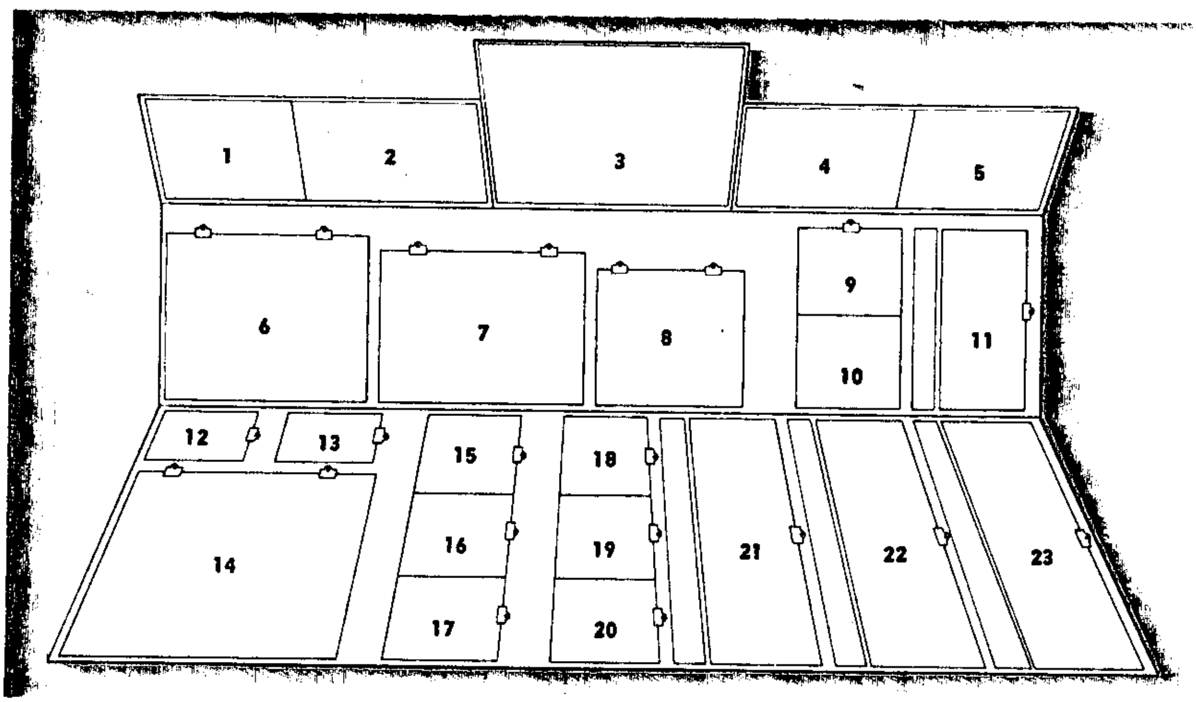
The type (s) of local distribution systems used vary a great deal depending upon the areal extent of the air terminal complex. Other than intercom and ordinary telephone, the ones widely used are:

- TelAutograph or Electrowriter
- Local Facsimile Circuits
- Interphone
- Local Teletypewriter Circuits
- Closed-Circuit Television

PRESENTING (INTERPRETING AND BRIEFING)

There is sometimes a fine line between what can be called "distributing" and what is called "presenting." Presenting usually means the interpretation of material received over the teletypewriter and facsimile circuits and the concise oral comments in logical sequence about observed and forecast weather conditions, refining and supplementing the "written copy" information as necessary. If the user determines the existing and forecast weather situation from the "written copy" without professional assistance, then the user has made his own interpretation and has briefed himself. In such cases, the weather information merely has been distributed or made available to him by the weather service. But in association with "self-briefing," a frequently used term in the weather services, the weatherman renders a valuable service by effectively displaying the "hard copy" material for the user (see fig. 125). This, of course, cannot be easily accomplished other than in a weather office.

A *good* briefing on weather has a number of important characteristics in addition to those already mentioned, which will be discussed in chapter 18. Here we are concerned primarily with the means of performing the "presenting" function.



1. Sunrise/Sunset Charts
2. Map Explanation Chart
3. Service "A" Circuit Chart
4. Explanation Aviation Weather Report
5. Explanation 4-Part Aviation Weather Forecasts
6. Weather Depiction Chart
7. Radar Summary Chart
8. Winds Aloft Chart
9. 18 Hour Surface Clouds—Precipitation Prog.
10. High Level Significant Weather Prog.
11. Relay Hourly and Special Aviation Weather Reports
12. PIREPS (Pilot Reports)
13. RAREPS (Radar Reports)
14. Surface Weather Chart
15. In-flight Advisories
16. FA's (Area Forecasts)
17. FA's (Area Forecasts)
18. FD's (Winds Aloft Forecasts)
19. FT's (24 Hour Terminal Forecasts)
20. FN's (Regional Forecasts)
21. FT 1's (12 Hour Terminal Forecasts)
22. Primary Hourly Aviation Weather Reports and Specials
23. Relay Hourly and Special Aviation Weather Reports

FIGURE 125. The WBAS aviation weather briefing display.

GROUND PRESENTATION

Weather Bureau Airport Stations and the weather offices of the Air Force and Navy offer complete ground weather briefing services by professionally qualified personnel. *Those offices of the military services normally serve military users only.* Almost all of these stations, Weather Bureau and military, have graphic (facsimile) products as well as the material distributed by weather teletypewriter circuits.

Additional pilot weather briefing offices are the Flight Service Stations (FSS) of the Federal Aviation Agency. Personnel at these facilities are trained aviation weather briefers as well as flight service specialists. Flight Service Stations eventually may have facsimile service.

The weather information available at civilian weather briefing offices is indicated in figure 126. Figure 127 shows the locations of weather briefing offices in the 48 adjoining States of all agencies.

Ways in which the pilot on the ground may receive a weather briefing other than by going to the weather office are presented below:

Recorded Weather Briefings. Pilots may receive *continuous broadcasts* of weather informa-

WHAT IS AVAILABLE

AT U.S. WEATHER BUREAU AIRPORT STATIONS

AND FAA FLIGHT SERVICE STATIONS

HOURLY AND SPECIAL WEATHER REPORTS FROM HUNDREDS OF AIRPORTS

PILOT REPORTS ON ICING, TURBULENCE, CLOUD TOPS, ETC.

U.S. WEATHER BUREAU AVIATION WEATHER FORECASTS

RADAR REPORTS OF SIGNIFICANT CONVECTIVE ACTIVITY

LATEST WEATHER CHARTS INCLUDING WEATHER DEPICTION (WBAS only)

WINDS ALOFT INFORMATION

WEATHER BRIEFING SERVICE FOR YOUR FLIGHT

Following Chapters illustrate how easily you can learn to read Aviation Weather Observations, Aviation Weather Forecasts, and Winds Aloft Forecasts, and use weather charts in your flight planning.

Through cooperative arrangements between the Weather Bureau and FAA, FAA takes weather observations at many airports which have no Weather Bureau Station and assists the Weather Bureau by providing weather briefing through Flight Service Stations. FAA Flight Service Specialists have had Weather Bureau training in pilot briefing.

FIGURE 126. Weather information available at briefing offices.

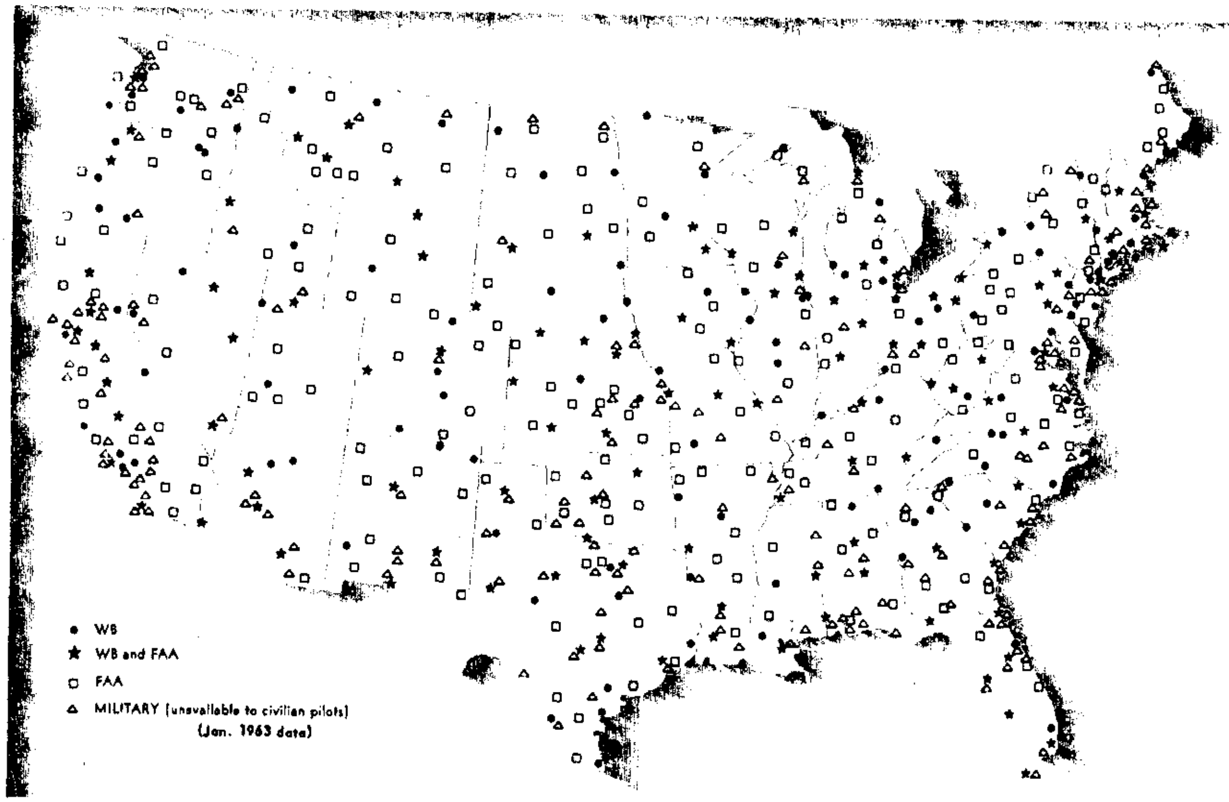


FIGURE 127. Weather briefing offices (person-to-person).

tion for a radius of 250 miles over many of the low and medium frequency navigation aids of the Federal Aviation Agency. Compact radio receivers for these frequencies are commercially available at nominal cost. The Weather Bureau provides the forecast script and radar information in this joint service. The Federal Aviation Agency's Flight Service Stations voice record the script, which is then automatically broadcast on the navigation aid frequency.

The Weather Bureau's *Pilot's Automatic Telephone Weather Answering Service (PATWAS)* provides information similar to that in the continuous weather broadcasts. The weatherman records a briefing, which is available to the pilot over his local telephone. In some areas, it is also available through toll-free, foreign exchange telephone service. Telephone numbers are not listed in telephone directories but are available to the pilot through the Airman's Information Manual. This practice is necessary to insure that unauthorized persons do not obtain the telephone numbers of this special service. The military weather services provide a recorded briefing of flight forecast information over a radius of 50 miles for military users through a similar method.

Locations of continuous transcribed weather broadcasts (TWEB) and PATWAS facilities are shown in figure 128. A sample script is given in appendix I.

Pilots who plan to fly only in the local area can obtain some weather assistance by dialing into the general-purpose weather forecast which is recorded by the local telephone company in fourteen major cities from a script furnished by the Weather Bureau. Provided as a public service by the telephone company, this forecast is available at Baltimore, Boston, Chicago, Cleveland, Detroit, Los Angeles, Milwaukee, New York City, Norfolk (Va.), Philadelphia, Pittsburgh, Richmond (Va.), San Francisco, and Washington, D.C. In a number of other cities, commercial sponsors provide a similar recorded general weather service by telephone.

Person-to-Person Telephone Briefing. The Weather Bureau provides weather briefings

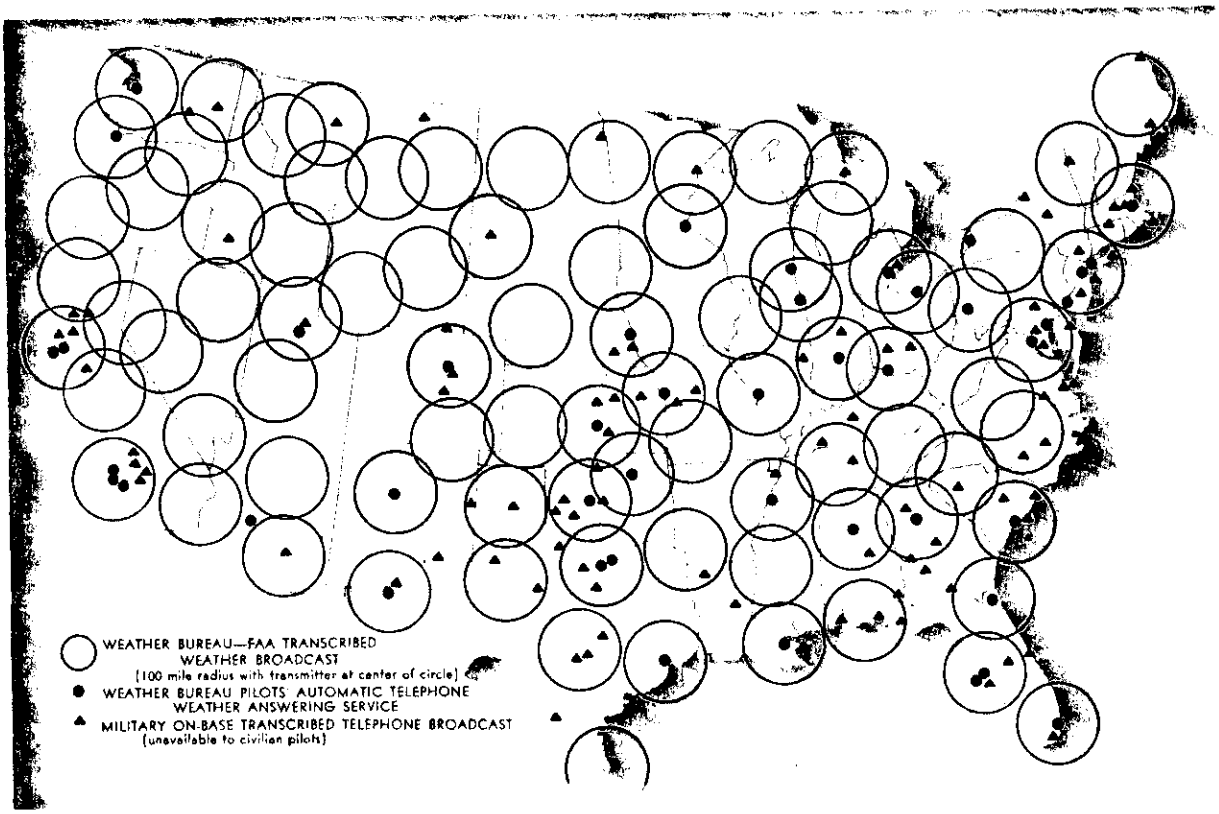


FIGURE 128. Ground briefing facilities (transcribed).

through both listed and unlisted telephone numbers. These are conversations (two-way) between the pilot and the briefer. The unlisted numbers for all Weather Bureau offices providing this service are published in the Airman's Information Manual. FAA Flight Service Stations also may be reached by telephone (numbers are listed in the Airman's Information Manual and in local telephone directories).

Briefing by Closed-Circuit Television. The Weather Bureau and FAA both have experimented to a limited extent with briefing by closed-circuit television, and it is likely that this briefing method will be used more commonly in the aviation weather service of the future. Since the pilot sees the charts on which the forecasts are made and hears them commented upon as well, television briefing is second only to face-to-face briefing in its effectiveness. In addition to scheduled briefings, pilots are provided a request-reply service. The military weather services have used this method of briefing effectively for some time.

IN-FLIGHT WEATHER BRIEFING SERVICES

FAA Request-Reply Service. Weather information may be received in flight by radio contact with Flight Service Stations of the Federal Aviation Agency. Locations of these facilities are included in figure 128. The Flight Service Specialist interprets the briefing material supplied by the Weather Bureau when answering an in-flight request the same as he does when briefing over the telephone or face-to-face.

When filing a VFR flight plan, the pilot may request FAA's flight following service. In addition to maintaining a radio watch for the pilot, the service relays pertinent weather information to him.

Weather Broadcasts. TWEB service on low and medium-frequency navigation aids is designed as a briefing service for pilots, mainly on the ground. This service, of course, is available as well to pilots in flight. In addition to TWEB's, weather reports and other aviation weather information are broadcast via Nav-Aid voice channels at 15 minutes and 45 minutes past the hour. SIGMETS and ADVISORIES FOR LIGHT AIRCRAFT are included in these scheduled broadcasts and, in addition, SIGMETS are broadcast unscheduled when first issued, on the hour, and at 30 minutes past the hour.

SUPPORTING FUNCTIONS

While those engaged in aviation climatology and weather research do not concern themselves with up-to-the-minute weather, their input into the aviation weather service is sizeable and very valuable. Without climatology, it would not be possible to present the average weather conditions which are illustrated in various places in this manual. Runways, for example, are oriented largely on the basis of wind history for that location. Long range planners must have intimate knowledge of the types of weather that can be expected during a planned operation or mission. Although day-to-day forecasts will be used when the operation is carried out, they of course are nonexistent when the plans are being developed weeks or months ahead of the target date. Climatic studies of past weather furnish an insight into the type of weather which can be expected during the pending operation.

CLIMATIC SERVICES

Partially supported by the Air Force and Navy, the Weather Bureau's National Weather Records Center at Asheville, N.C., collects, tabulates, and stores weather data from all parts of the world. Weather data are stored on punch cards for later computer processing. This makes the necessary information readily available when needed for climatic studies.

The Office of Climatology near Washington, D.C., is a large part of the overall Weather Bureau, providing a great variety of services for a large number of different interests, such as agriculture, commerce, aviation, etc. The Air Force's Climatic Center, also in Washington, D.C., services military requirements for the application of weather history to operating problems.

Typical of the services of the Weather Bureau's Office of Climatology is the study being made to determine the most favorable air routes and terminals for supersonic transport aircraft operations. Another important study among many is directed toward increasing the weather forecaster's knowledge of past weather vagaries at air terminals and along air routes now in use. This should result in forecast improvement.

RESEARCH AND DEVELOPMENT

To treat each individual aviation weather research and development project being conducted by the government would indeed make this a lengthy discussion. The Federal Aviation Agency, the military weather services, and the Weather Bureau all contribute toward meeting the present and the anticipated future requirements of all users of aviation weather information. The common goal is to furnish all needed weather elements, both current and forecast, with the greatest possible degree of the following:

Timeliness
Representativeness
Accuracy
Completeness
Applicability to specific uses
Clarity

The *operational* functions of the nation's aviation weather services organization are diagrammed in figure 129.

SERVICE TO INTERNATIONAL AVIATION

Service for international flights is provided in accordance with recommended procedures established by the International Civil Aviation Organization (ICAO) of which the United States is a Contracting State. The Weather Bureau is the agency of the United States responsible for

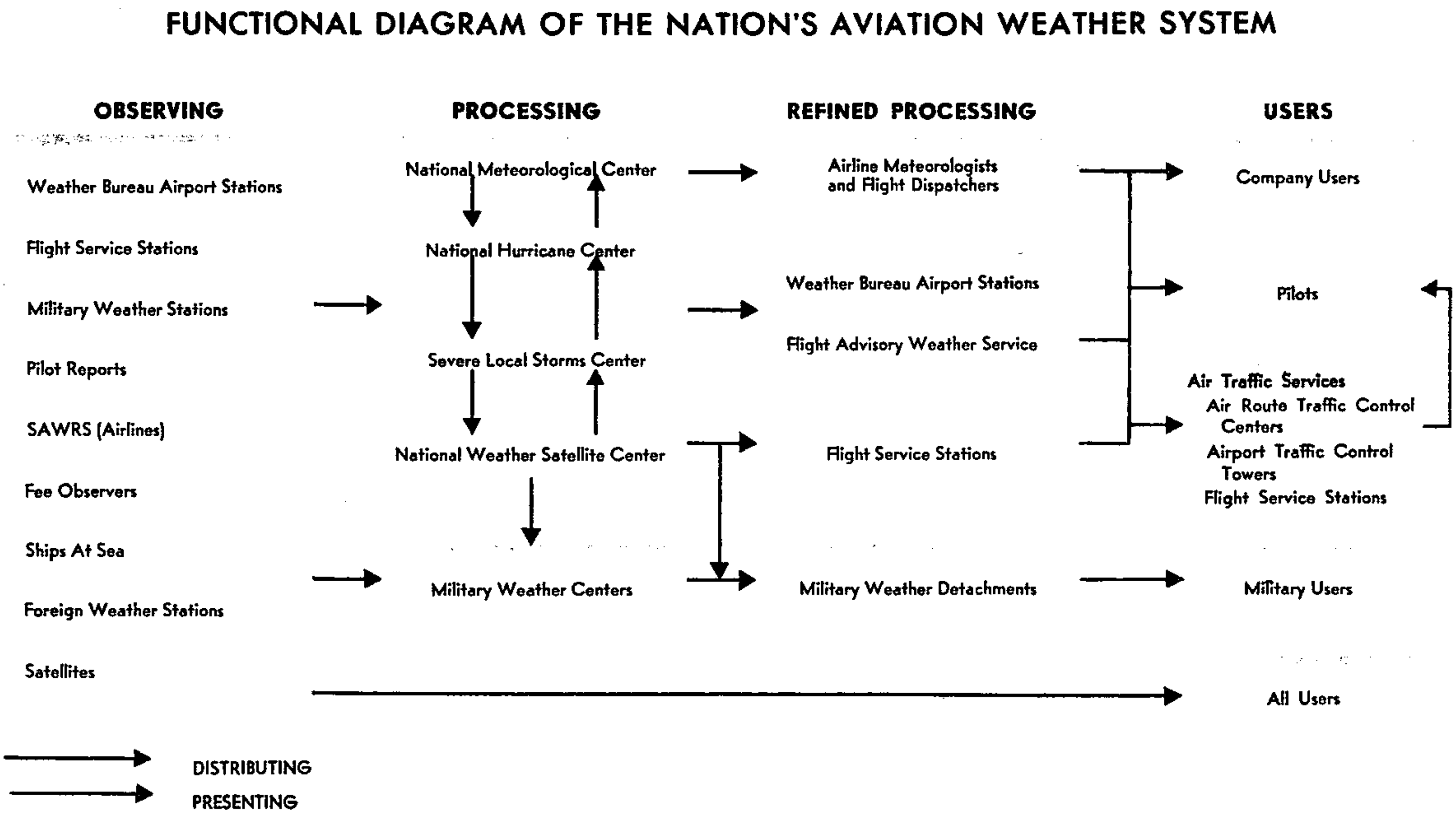


FIGURE 129. Functional diagram of the Nation's aviation weather system.

providing or arranging for weather service for international air navigation. The High Altitude Forecast Centers, discussed earlier in this chapter, are the principal operational units which have been established to carry out this responsibility. Under ICAO regulations, weather offices are divided into four categories as follows:

MAIN METEOROLOGICAL OFFICES (MMO's)

These offices supply any or all weather information specified in ICAO procedures. Weather Bureau offices (High Altitude Forecast Centers) at Anchorage, Honolulu, Miami, New York, San Francisco, and San Juan fall into this classification.

DEPENDENT METEOROLOGICAL OFFICES (DMO's)

These offices supply a limited amount of information on their own initiative, but they are dependent on their associated MMO for basic material and guidance. Philadelphia, Houston, and Los Angeles are examples of DMO's.

SUPPLEMENTARY METEOROLOGICAL OFFICES (SMO's)

These offices supply documentation containing flight and terminal forecasts received from the associated MMO or DMO and such other weather information as may be available. Examples of SMO's are Buffalo, Milwaukee, and St. Louis.

METEOROLOGICAL WATCH OFFICES (MWO's)

These offices maintain a watch on weather conditions over an assigned area, usually a Flight Information Region, and issue advisory information as described in later paragraphs. All of the Weather Bureau's MMO's are also MWO's. Other MWO's are New Orleans, Seattle, and Wake Island, Pacific.

CONTENT OF SERVICE

Service for international aviation basically consists of operational planning information, briefing, documentation, an area weather watch, which includes the issuance of significant meteorological information (SIGMETS) as necessary, and weather broadcasts. Each of these will be discussed briefly.

Operational Planning Information. This service consists of providing information in any of the following three categories:

(1) Preliminary operational planning. Information made available up to 24 hours prior to the flight's estimated departure time includes: (a) Expected developments in the general weather situation; (b) forecasts for planned destination and alternates; (c) expected upper winds and temperatures; and (d) any significant weather expected over the route.

(2) Preflight operational planning. This information consists of essentially the same as in (1) above, including any necessary amendments. Available three hours in advance of the ETD, the information normally will be the same as that appearing in the flight folder given the crew with the briefing.

(3) Operational planning for aircraft in flight. This information, consisting of any or all of the following items is provided when requested by an in-flight aircraft:

a. Routine and special reports
b. Terminal forecasts and amendments
c. Landing forecasts
d. SIGMET information
e. Upper air information

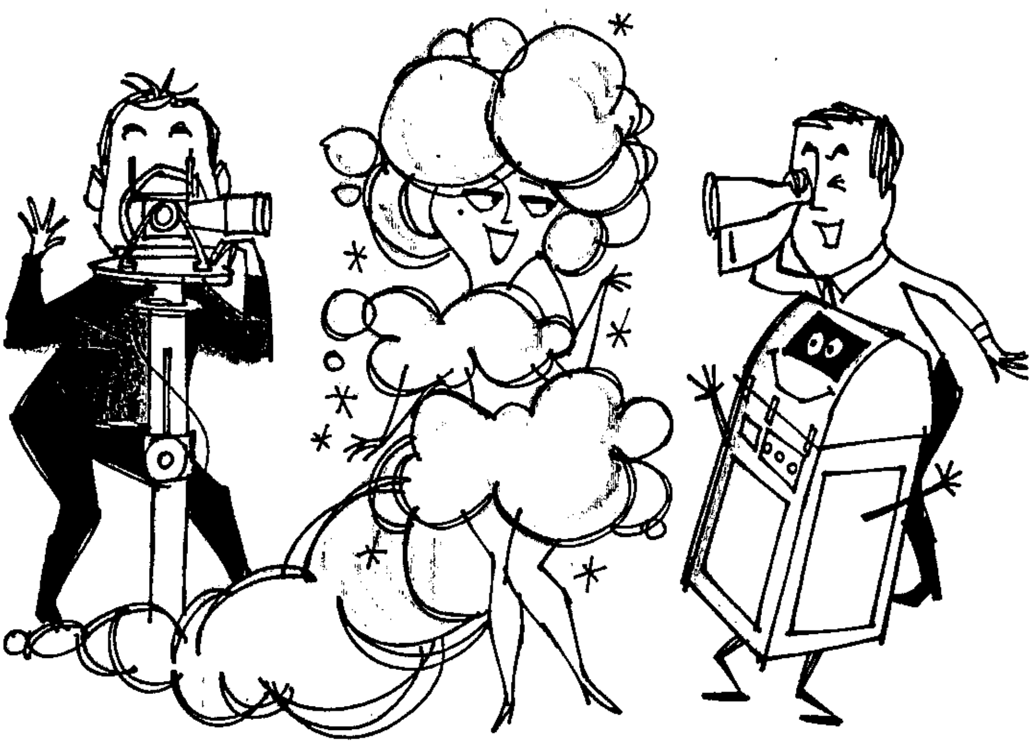
Briefing. Briefing for international aviation is basically the same as that for domestic aviation. Accompanying the verbal briefing is a display of the flight documentation items (discussed below), other charts and cross-sections that may be available, and reports of significant weather conditions which are anticipated but are not shown on the charts.

Documentation. The flight documentation includes: (1) Prognostic constant pressure charts for at least two levels, (2) a prognostic significant weather chart (described in ch. 16), and (3) terminal forecasts (received via international exchanges) for at least three airports (planned destination and two alternates).

SIGMETS. SIGMETS are issued by Meteorological Watch Offices (MWO's) when any of the following conditions are considered imminent: (1) Active thunderstorm area, (2) tropical revolving storm, (3) severe line squall, (4) heavy hail, (5) severe turbulence, (6) severe icing, (7) marked mountain waves, and (8) widespread sandstorms/duststorms.

Weather Broadcasts. VOLMET broadcasts include hourly weather reports for several terminals in arrival areas. These routine broadcasts, originating from key terminals, are made every half hour for a period of 5 minutes. Some VOLMET broadcasts include terminal forecasts and current SIGMETS.

SIGMETS are broadcast upon issuance by Meteorological Watch Offices. Later terminal forecasts and changes in enroute winds, temperatures, and significant weather for the latter half of the flight may be obtained upon radio request from the in-flight aircraft.



Chapter 15
WEATHER OBSERVATIONS

Weather observations of various types in combination with one another are needed to give both the weatherman and the pilot a three-dimensional picture of existing weather conditions. The number and types of observations required depend on the pilot's individual needs. For example, a pilot flying only in a local area does not need a weather picture of the entire United States. Or, if he is flying at 4,000 feet, most likely he is unconcerned about high tropospheric conditions.

The airborne pilot has a distinct advantage over a ground observer in making weather observations. Not only does the pilot usually have a broader horizon, but, if he is flying above a cloud layer, he may see higher clouds or other phenomena which probably are unknown to the ground observer.

Atmospheric soundings provide valuable information to the weatherman, but the airborne pilot still has a better vantage point for seeing what "Mother Nature has wrought."

This chapter includes a detailed discussion of information contained in the various types of observations and indicates how the information may be interpreted from the codes, symbols, and contractions in which it is distributed. Also included is a brief discussion of the method of observing or (when applicable) measuring each weather element. This information should help the pilot to fully understand the limitations of observations made from the ground in providing the total weather picture.

SURFACE WEATHER OBSERVATIONS

Surface weather observations are made routinely and are distributed at scheduled hourly intervals. Special observations of the same type are distributed when the weather changes significantly between scheduled observations. Called "Aviation Weather Reports," surface observations are made this often primarily because of aviation's need for up-to-date weather information.

Surface observations at scheduled 3- and 6-hour intervals, called "Synoptic Reports," contain information of interest primarily to the analyst and forecaster. These reports are made and distributed in a code form entirely different from that used for the hourly aviation observation. Synoptic Reports are received from ships at sea and from all land areas of the world. Pilots benefit from knowing the basic weather symbols (see fig. 130) used in plotting Synoptic Reports on surface weather charts. Only pilots traversing large ocean spans for which Aviation Weather Reports are unavailable need concern themselves with further interpretation of Synoptic Reports. The basic weather symbols, however, are used on other graphic material prepared locally or received by facsimile.

Other common names for Aviation Weather Reports, the surface observations most useful for pilots, are "hourly teletypewriter sequences," "hourly collections," "weather sequences," and "hourly surface reports."

FIGURE 130. Basic weather symbols used on weather charts.

On examination of these cryptic Aviation Weather Reports, one finds that the mystery is removed by learning the symbols and contractions. These symbols have been simplified as much as possible for ease of reading and for compactness.

The Aviation Weather Report which appears below is much more complex than the average ones. It is selected as an example to demonstrate that even the complex ones can be interpreted without a great amount of difficulty. As in the case of all teletypewriter copy printed in this manual, zeroes are open. Some Service A teletypewriters use zeroes with a slant bar (/) running through them; others do not.

023 SA23212100
DIA 15⦶M30⊕1/2VRW−F 152/68/60/
3018G30/996/VR28 WSHFT 1548E/⊕65/
⊕V⦶ RB05 DRK NW VSBY 1/4V3/4
→DIA 9/5 QAPES ↘9/1

The understanding of the above report is made easier if it is discussed in segments. The table in the back of this manual explains not only this report, but the meaning of almost any such report which may be encountered. The table may be extracted from the manual and placed where desired for handy reference.

DETERMINATION OF VALUES OF WEATHER ELEMENTS

A pilot who understands the methods of making weather observations can evaluate the degree of reliability in a given report. For example, he would trust a report of ceiling indicated as "measured" more than one which is "estimated," although either, in conjunction with visibility, determine whether VFR flights are authorized. The various methods used for determining values of weather elements in an Aviation Weather Report are presented below:

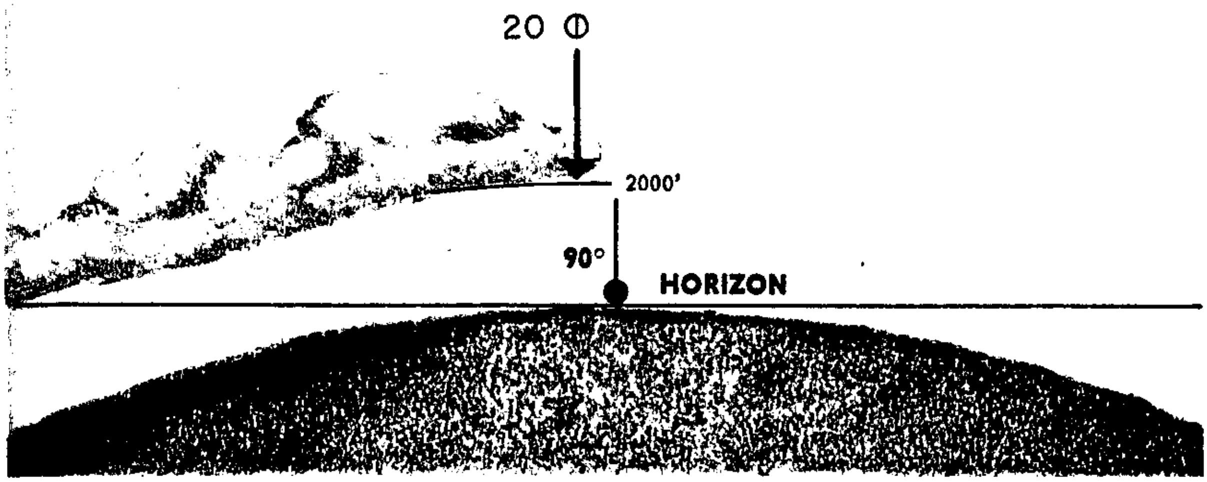


FIGURE 131. Sky cover determination (single cloud layer). (In this example of an advancing cloud layer, the sky cover is 5/10.)

Sky Cover and Ceiling. The observer estimates the amount, in tenths, of the total sky, within his horizon, which is covered by clouds or by obscuring phenomena (either surface-based or aloft). Figures 131 and 132 show two differing examples of a sky which would be considered by the observer as half-covered with clouds. Since six-tenths or more of the sky must be covered in order for the cloud layer to be classified as broken (or overcast), in both examples the sky condition would be reported as scattered clouds at 2,000 feet.

When two or more cloud layers are present, the summation principle is applied (illustrated in figs. 133 and 134). It is especially important for the pilot to understand that a report of

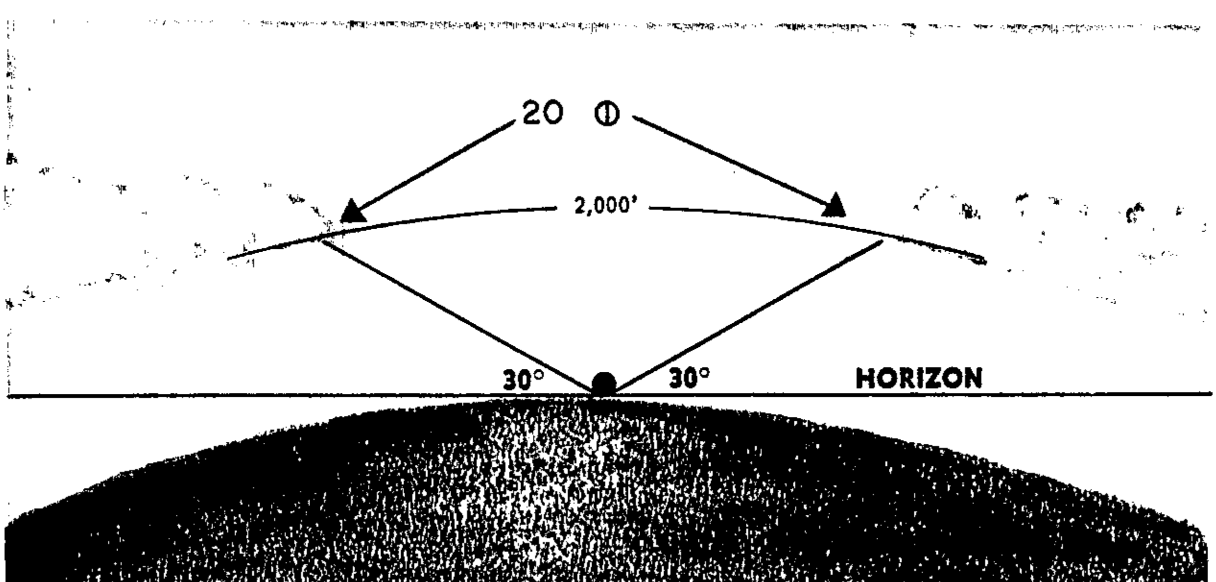


FIGURE 132. Sky cover determination (single cloud layer). (The sky cover also is 5/10 in this example of a cloud layer surrounding the station.)

broken or overcast clouds at a particular height above the ground does not necessarily indicate that the cloud layer *at that altitude* actually covers six-tenths or more of the sky. The surface-based observer often does not know the actual extent of higher cloud layers. He uses the summation principle to report the amount of sky covered by clouds at each level. This involves adding the amount covered at lower levels to the apparent amount of sky cover at higher levels. Thus an upper layer, which by itself would be considered scattered, will be reported as broken if the *total* summation at that level is six-tenths or more.

The amount of sky cover reported determines whether a layer is described as scattered, broken, overcast, partial obscuration, or obscuration. The ceiling will be the lowest layer that is reported as broken or overcast and not classified as thin, or obscuration not classified as partial.

Several procedures are employed for determining the height of clouds above the ground. Experienced observers often can make very good estimates. Balloons with a known ascension rate can be released and observed until the cloud base is reached. The time between release and entry into clouds provides a measurement of the cloud height. Most Weather Bureau stations employ ceilometers which provide continuous indications of cloud heights. In addition, surface-based radar on occasion can supply both the base and top of a cloud layer.

In measuring the height of a cloud base with ceiling lights and fixed-beam ceilometers, a beam of high-power light is projected vertically against the cloud base. The height of the base is computed on the basis of (1) the known distance between the light projector and the observing point, and (2) the measured angle between the horizon and the place where the beam of light

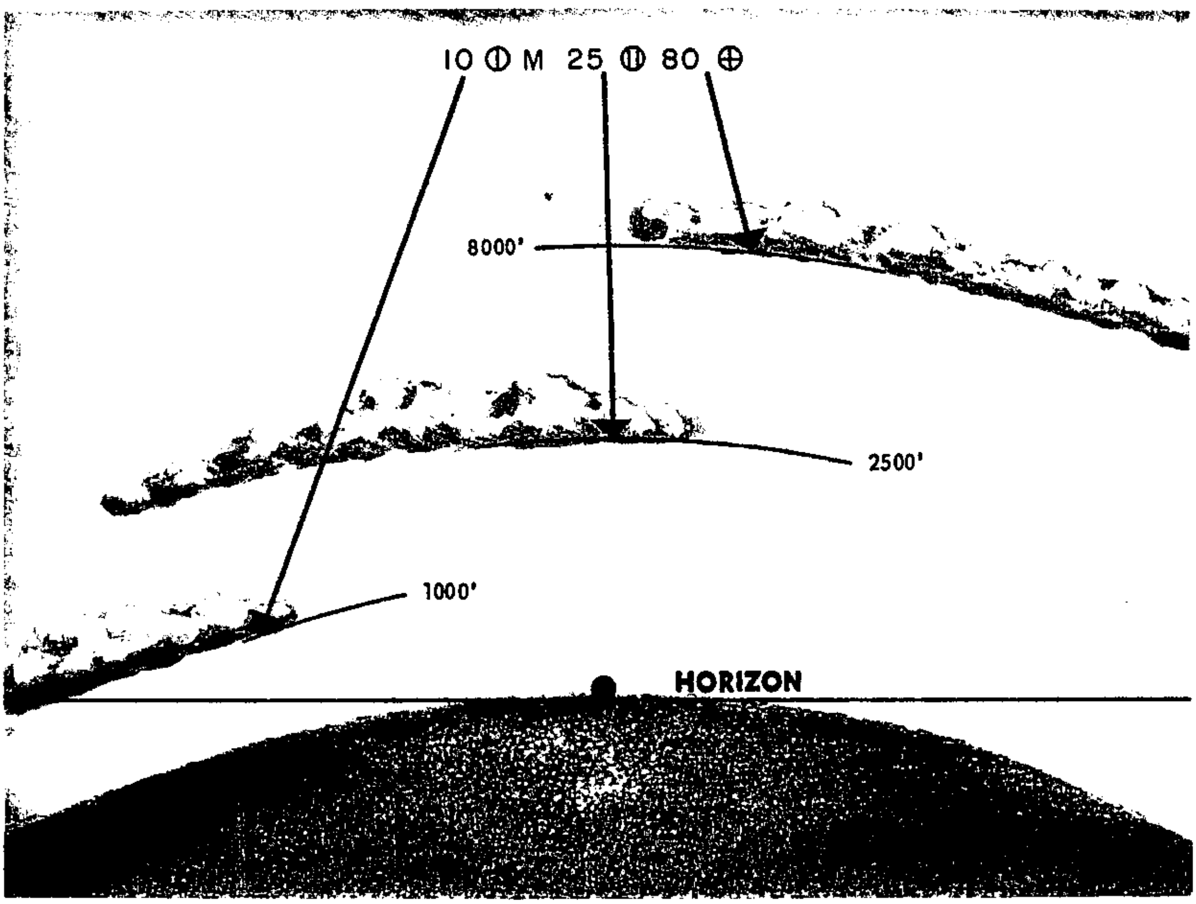


FIGURE 133. Summation of cloud cover. (Note that the upper layer is reported as overcast even though it alone covers less than 1/2 of the sky.)

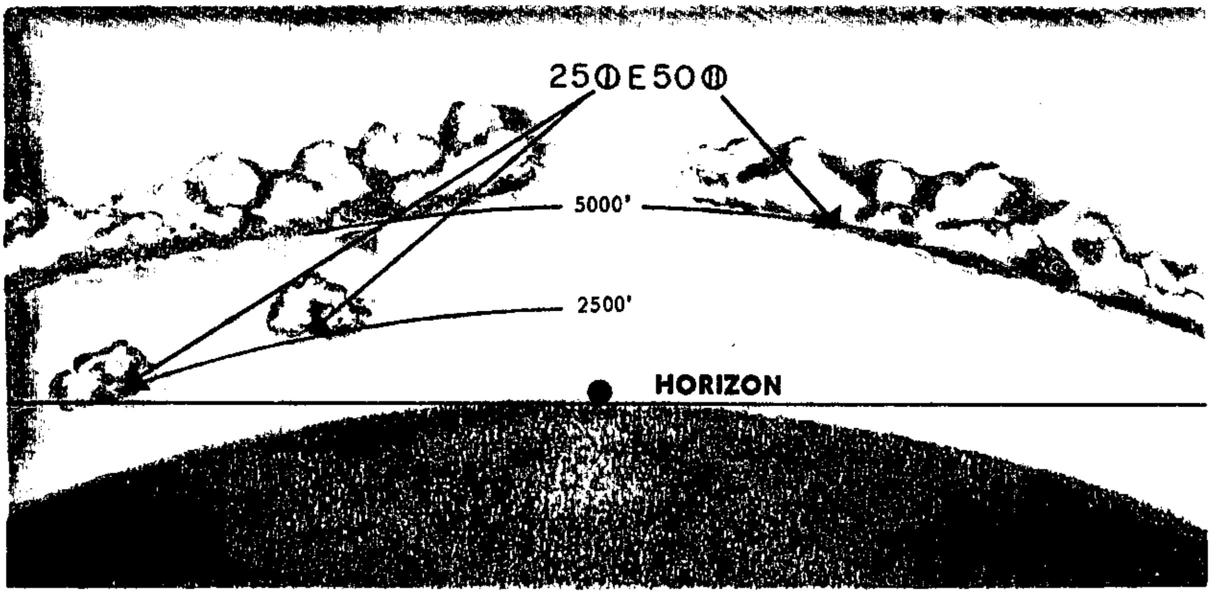


FIGURE 134. Summation of cloud cover.

intersects the cloud (see fig. 135). In the case of the ceiling light, this angle (elevation angle) is measured manually by the observer with a clinometer. The ceilometer is a more advanced instrument, automatically recording the elevation angle from which the cloud height is computed. Another important advantage of the ceilometer is that it may be used during daylight as well as at night.

The rotating-beam ceilometer represents a further improvement toward the accurate determination of the height of cloud bases. Rather than being projected in the vertical only, the beam of light is scanning continuously in a ver-

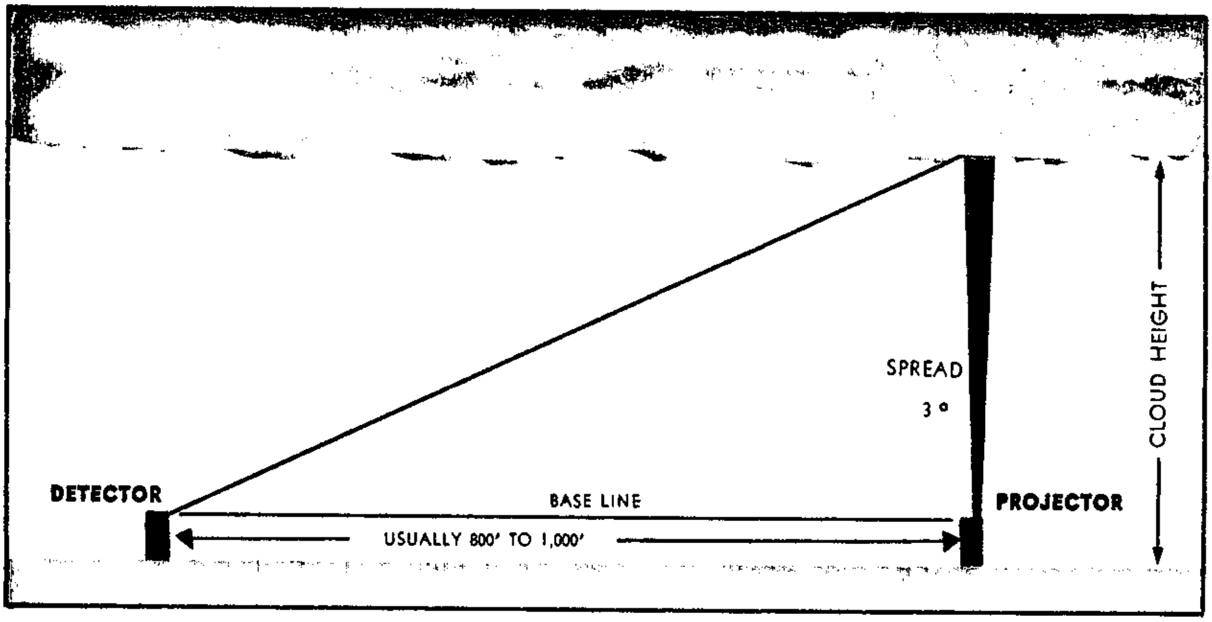


FIGURE. 135. Fixed beam ceilometer system.

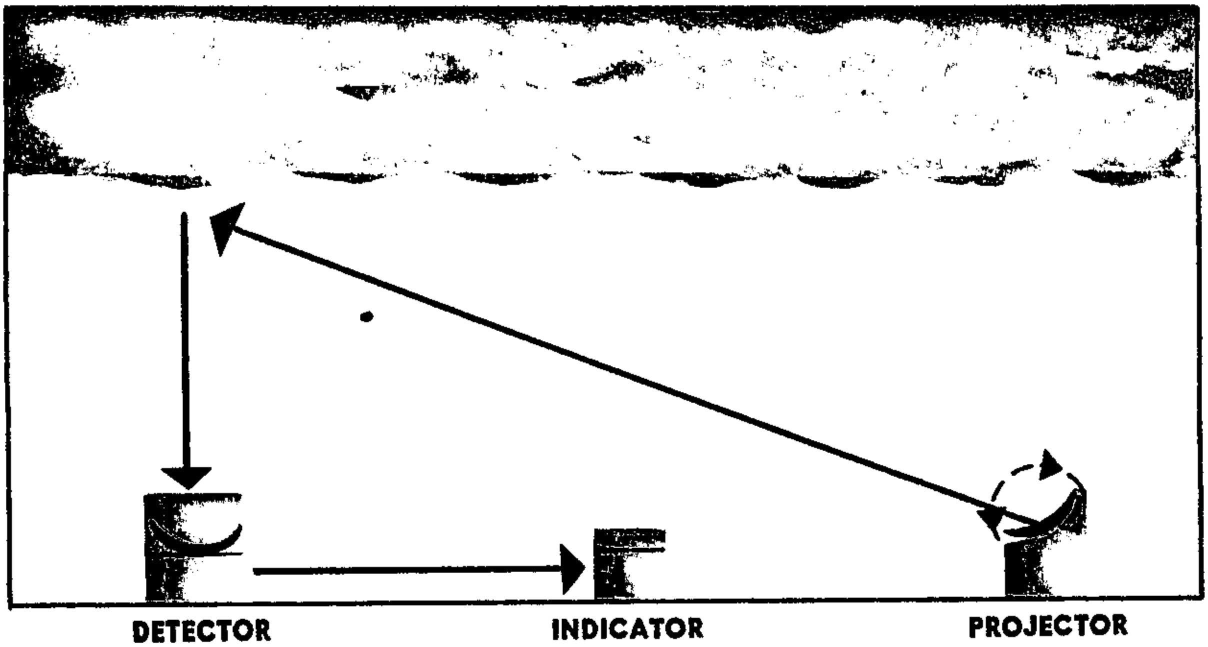


FIGURE 136. Rotating beam ceilometer system.

tical plane (see fig. 136). Similar information to that provided by the fixed-beam ceilometer is obtained at more frequent intervals by the rotating-beam ceilometer. The rotating-beam ceilometer is located at the middle marker at most airports that are equipped with instrument landing systems.

Visibility. Meteorological visibility is the greatest horizontal distance at which selected objects can be seen and identified. This distance is not always the same in all directions. For this reason, the "prevailing" value is included in Aviation Weather Reports. In addition to a further explanation of prevailing visibility, the discussion below includes visibility determinations which are more directly applicable to aircraft landing and takeoff operations.

PREVAILING VISIBILITY

The greatest horizontal visibility, in miles and fractions, which is equalled or surpassed throughout at least half of the horizon circle is

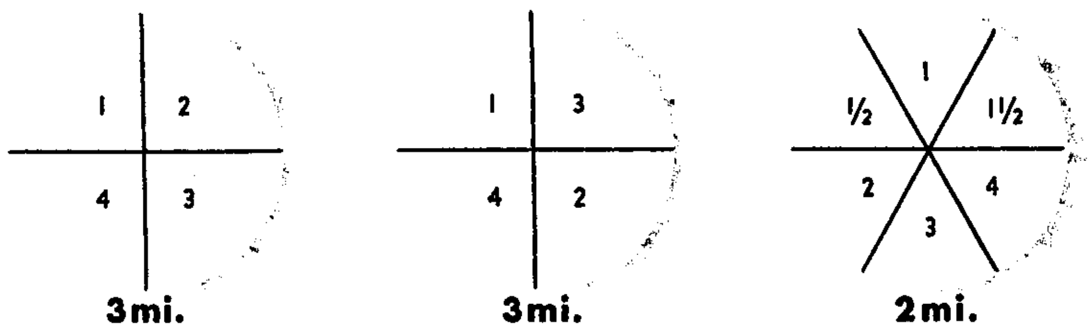


FIGURE 137. Determination of prevailing visibility.

the prevailing visibility. The segments making up this half of the horizon circle need not be adjacent to one another. Figures 137 and 138 illustrate examples of the determination of prevailing visibility.

In addition to visibility reports from the regular weather observer at an airport, reports also may be received from control towers (illustrated in fig. 139).

RUNWAY VISIBILITY

"Runway visibility" (RVV) is the meteorological visibility in one direction, expressed in miles and fractions, observed along a specific runway. Usually determined by a transmissometer, a given runway visibility is applicable only to the runway or runways with which the instrument is associated. Figure 140 shows the components of a transmissometer installation. *The instrument, in this case, is calibrated in* terms of a human observer—that is, the sighting of dark objects against the horizon sky during daylight, and the sighting of moderately intense unfocused lights of the order of 25 candle power at night.

Some automatic weather stations at nonairport locations report a directional visibility value which corresponds to runway visibility, in lieu of prevailing visibility.

Runway visibility, as a supplement to prevailing visibility, appears in the *remarks* section of Aviation Weather Reports from authorized stations when the transmissometer value is less than specified values, usually near 2 miles. The following examples of reported runway visibility are interpreted as shown below:

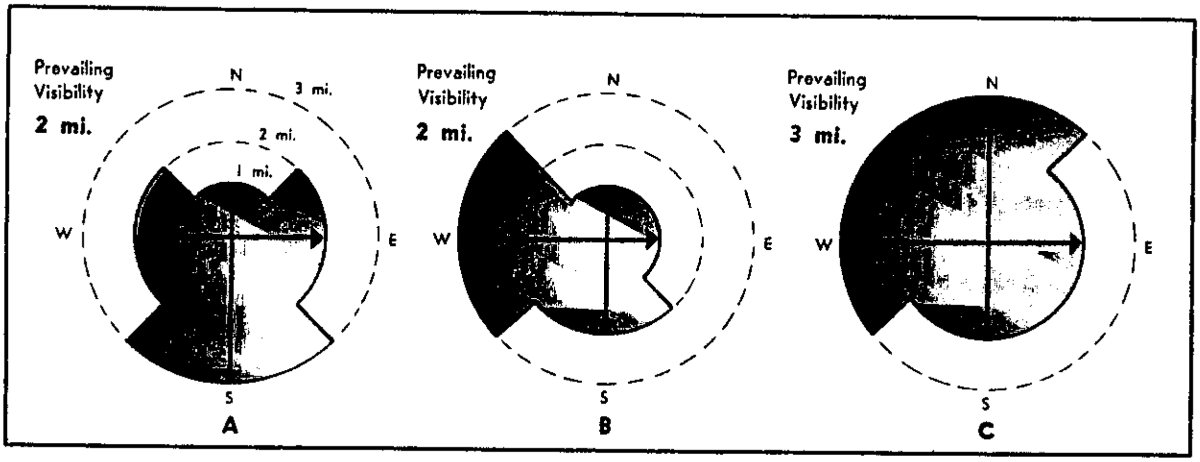
R25VV11/2V2 is decoded as RUNWAY TWO FIVE, VISIBILITY VARIABLE BETWEEN ONE AND ONE HALF (miles) AND TWO (miles).

If the value reported were not associated with a runway, the above report would appear as RNOVV11/2V2.

RUNWAY VISUAL RANGE

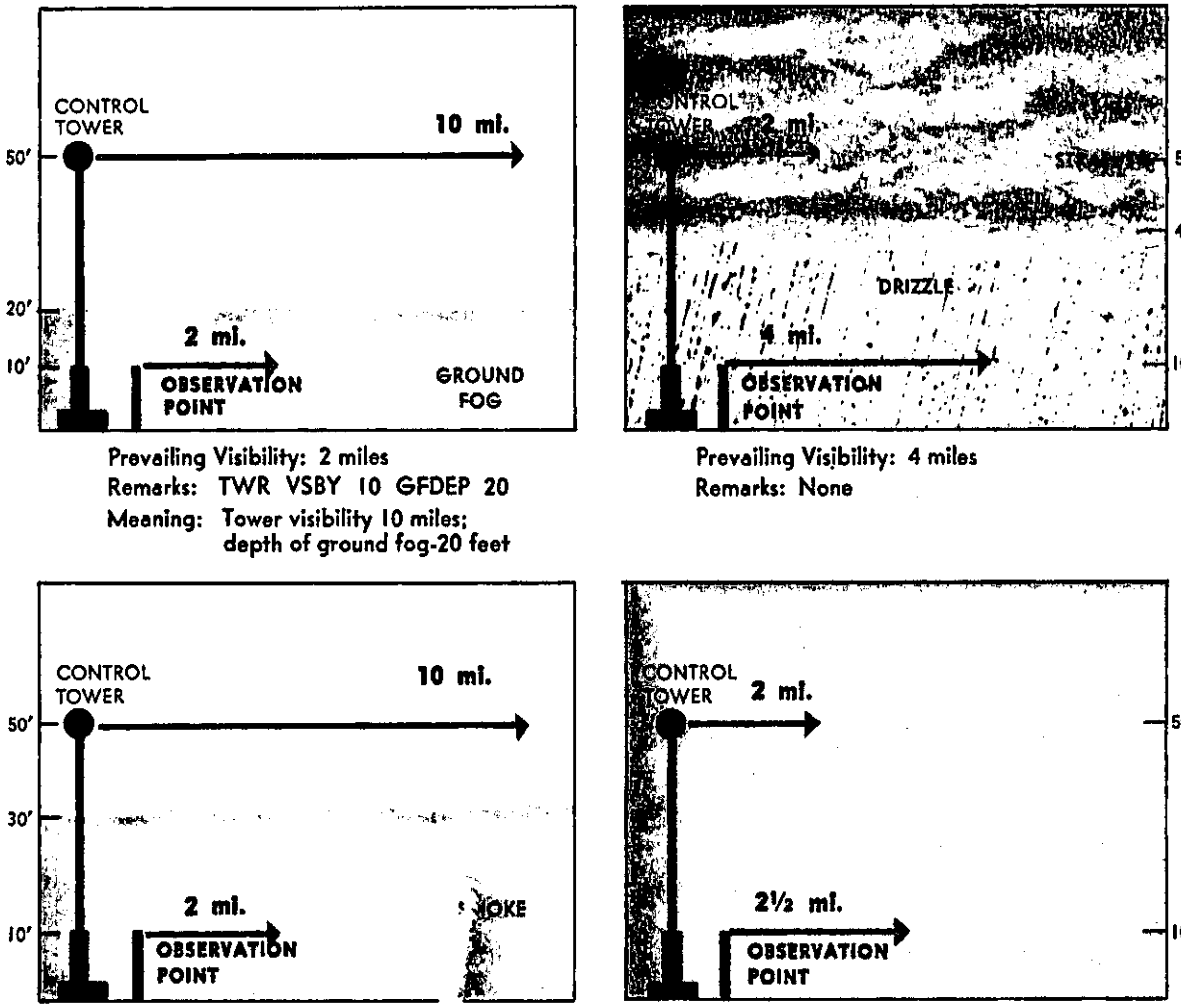
In the United States, runway visual range (RVR) is an instrumentally derived value, based on standard calibrations, that represents the horizontal distance a pilot can see down the runway from the approach end; it is based on the sighting of either high intensity runway *lights or on the visual contrast of other targets* —whichever yields the greater visual range.

Expressed in hundreds of feet, runway visual range capitalizes on the increased guidance which intense runway lights give the pilot. It is determined from a transmissometer system installed along an instrument runway. As the runway light setting is changed by tower personnel, the transmissometer's computer system, wired directly to the lighting control, automatically converts the readout to a value based on the new light setting. Although a particular pilot may be able to see slightly more or less



NOTE: The limits of visibility are represented by the red area.

FIGURE 138. Determination of prevailing visibility.



Prevailing Visibility: 2 miles
Remarks: TWR VSBY 10 GFDEP 20
Meaning: Tower visibility 10 miles; depth of ground fog-20 feet

Prevailing Visibility: 4 miles
Remarks: None

Prevailing Visibility: 10 miles
Remarks: SFC VSBY 2 KDEP 30

Prevailing Visibility: 2 miles
Remarks: SFC VSBY 2½

A remark may also be included to report runway visibility, if required.
e.g. SFC VSBY 2 KDEP 30 VSBY 1 RNWY 36

FIGURE 139. Visibility at different levels.

than the indicated runway visual range, this instrumentally derived measurement is normally more representative than an evaluation by eye, based on visibility targets usually available. Runway visual range represents the most objective method in use to let the pilot know the distance he may expect to see when landing or taking off in poor weather conditions (see fig. 141). Runway visual range (RVR) is reported as the first item in the *remarks* section of Aviation Weather Reports from authorized stations whenever:

(1) The prevailing visibility is less than 2 miles and/or

(2) Runway visual range is 6,000 feet or less. The transmitted RVR value is a *mean* (average) determined over the 10-minute period preceding the time of observation. For local airport operations, the 1-minute mean value is used.

Precipitation and Obstructions to Vision. Types of precipitation are determined visually. Particles of precipitation, called "hydrometeors," are classified according to their size, their state

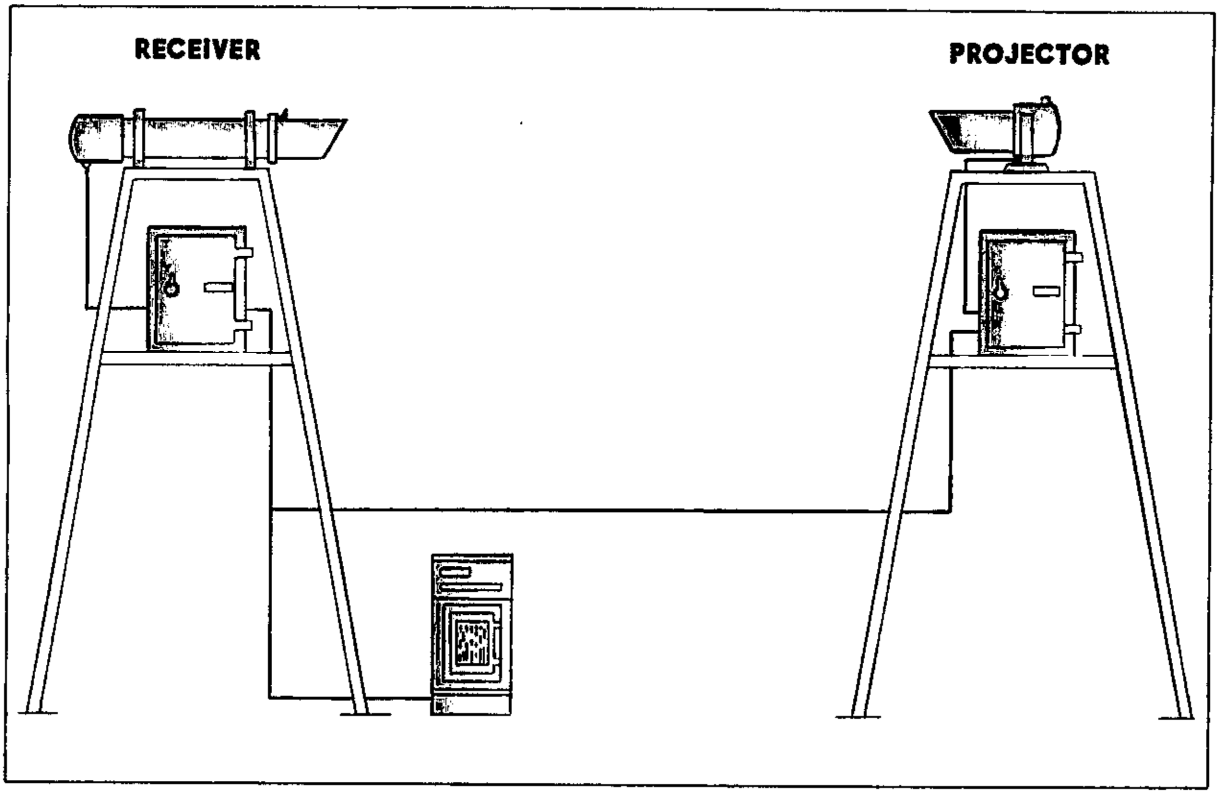


FIGURE 140. The transmissometer system.

(liquid or solid), and other characteristics. The intensity of precipitation is determined either on the basis of rate-of-fall, or according to the visibility present at the time.

The type of visual obstruction is determined by eye, and it is sometimes difficult to distinguish one form of obstruction from another. For example, haze and smoke often look very much

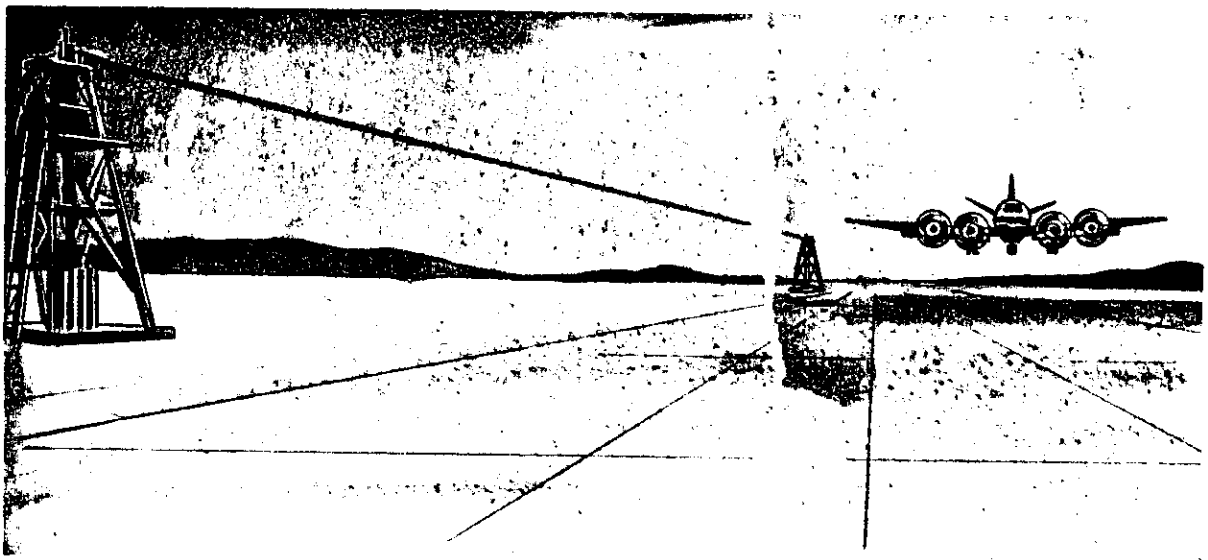


FIGURE 141. Runway visual range.

alike, and the observer must use his knowledge of local effects in making his determination.

Atmospheric Pressure and Altimeter Settings. Both aneroid and mercurial barometers are used to measure the atmospheric pressure. The aneroid barometer, of course, is the more portable of the two. The microbarograph, a precision aneroid barometer equipped with a clock and a rotating drum, offers the advantage of providing a continuous record of pressure.

The atmospheric pressure reported in an Aviation Weather Report is the pressure at the observing station reduced to mean sea level. The pilot is more interested in the altimeter setting than he is in the pressure at sea level. Expressed in inches of mercury and reported to the nearest hundredth, the altimeter setting is simply the pressure measured at the *station* and reduced to a height of 10 feet above mean sea level. The altimeter indicates zero altitude at an elevation of 10 feet above mean sea level. Thus, at the height of 10 feet above the airport elevation (average cockpit height), the altimeter should indicate the airport elevation. The reduction of pressure read in the weather station to that at 10 feet above mean sea level is based upon the *I*nternational *C*ivil *A*viation *O*rganization Standard Atmosphere, which is the basis for altimeter design.

Aneroid altimeter setting indicators are widely used as an immediate source of local altimeter settings. Such indicators are pressure actuated devices analogous to mercurial barometers, but with a mechanism that permits direct indication of the existing local altimeter setting, which varies with the station pressure. Correct altimeter settings depend upon periodic comparison with barometers of known accuracy. On the basis of such comparisons, the instrument is preset to accord with the existing station elevation and its point of installation.

Temperature and Dew Point. Almost everyone has a liquid-in-glass thermometer and frequently reads the temperature. The reported dry-bulb temperature is the natural temperature of the atmosphere near the Earth's surface as indicated by a thermometer of much higher quality than the average one hanging at home. By evaporating water from a wick-covered thermometer bulb and comparing the resulting reading (wet-bulb temperature) to the dry-bulb temperature, the observer determines the dew point temperature (usually called simply the "dew point") and the humidity of the air.

In common use are several types of recording sensors which provide direct indications of temperature and dew point. The most advanced of these is the hygrothermometer, a much-improved instrument for determining atmospheric moisture above relative humidities of about 15 percent. Since it also provides temperature measurements, the hygrothermometer usually is installed near the center of the airport's runway complex in order to provide values representative of those actually experienced by aircraft on the runways. The length of runway required for a jet aircraft takeoff is greatly influenced by the temperature and moisture content of the air, the most variable of factors determining the air's density.

Wind. Wind direction, speed, character (gusty or squally), and shifts are determined instrumentally at most weather stations. At stations without instrumentation, or where wind instrumentation is temporarily inoperative, the elements of the wind report must be estimated. In these uncommon situations, the Aviation Weather Report signifies that the wind direction and speed are estimated by displaying an E at the end of the two digits indicating wind speed (or gusts, if present). Most stations are equipped with wind vanes to measure wind direction and wind shifts, and cup anemometers to measure wind speed and gustiness.

Gustiness is characterized by sudden, brief increases in wind speed. It is not reported unless the variation between peaks and lulls is at least 9 knots. The average time interval between peaks and lulls usually does not exceed 20 seconds. When the wind is gusty, the speed of the peak gust during the past 15 minutes is reported following the usual report of average 1-minute speed. For example, "20G30" means that the 1-minute average wind speed is 20 knots, and the peak speeds in gusts are 30 knots. The occurrence of gusts or squalls indicates that the air near the surface is turbulent. A squally condition is reported if the wind increases suddenly in speed, maintains a peak speed of 16 knots or more for 2 or more minutes, and then decreases. A wind of 20 knots with peak gusts to 30 knots in squalls would appear in the appropriate position in the Aviation Weather Report as "20Q30."

The reported wind direction is that direction in reference to *true north* from which the wind is blowing. Normally, it is the prevalent direction over a 1-minute interval. Regardless of the type of wind indicator used, the gustiness or squall reported is the peak speed observed during the last 15 minutes prior to the time of the observation.

A pilot preparing to take off or approaching to land needs to know the wind direction in reference to *magnetic* north because runways are oriented on this basis. The wind direction stated in the regular space for wind information in Aviation Weather Reports is always in reference to *true* north, but the *magnetic* wind direction at the local airport is given in air-ground conversations between pilots and airport traffic control personnel. Wind directions at other locations are given in reference to true north.

Remarks. The "remarks" portion of an Aviation Weather Report often contains information which is as important as that included in the main body of the report. Remarks are added at the end to cover unusual aspects of the weather, as well as pertinent information for pilots, air traffic control personnel, and weathermen. Many remarks are mandatory, while others are added if considered valuable by the observer.

Methods of reporting various elements in the remarks section are changed more frequently than any other instructions to observers pertaining to surface weather observations. The typical pilot cannot easily keep up-to-date on these frequent changes. However, he can assume that the observer will report any additional known information of importance to flight operations in the remarks section of the hourly observation, or, if the condition warrants it, in special observations.

"Notices to Airmen" (NOTAMS) often are transmitted along with the observation by the Flight Service Specialist who transmits the Aviation Weather Report over the long-line teletypewriter circuit. NOTAMS consist of information of operational significance, such as the status of certain navigational aids.

Insofar as the information is available and its transmission is authorized, data are appended in the remarks section of nonmilitary Aviation Weather Reports in the following order:

(1) Runway visual range or runway visibility.

(2) Obscuring phenomena. For example, "FK4" would be translated as "fog and smoke obscuring 4/10 of the sky."

(3) Wind shifts.

(4) Heights (above mean sea level) in hundreds of feet of bases and tops of sky-cover layers not visible at the station. These remarks usually originate from pilots, but may be radar-determined. For example, "⊕30/60⊕" would be translated as "top of lower overcast 3,000 feet, base of higher overcast 6,000 feet."

(5) Remarks pertaining to coded elements which have been reported in preceding sections. For example, "CIG 25V35" would pertain to the ceiling reported near the beginning of the observation, and would be translated as "ceiling variable between 2,500 and 3,500 feet."

(6) 3- and 6-hourly scheduled code groups. This information normally is directed to weathermen.

(7) Freezing level data (RADAT). This information is obtained twice daily at stations that regularly make rawinsonde observations. It is transmitted in the remarks section of the Aviation Weather Report usually at 0100 or 0200 GMT and at 1300 or 1400 GMT. "RADAT 82053 0613C" would be translated as follows:

RADAT—A contraction to identify that freezing level data follow in numerical form.

82—The relative humidity in percent at the lowest freezing level. The digits 00 would represent 100 percent, and the digits 20 would represent 20 percent or less.

053—The height of the lowest freezing level shown by the sounding in hundreds of feet above mean sea level. In this example, the height of the lowest freezing level is 5,300 feet.

0613C—The time (local standard) that the data were obtained. The time is omitted if less than 1 hour elapses between the time the freezing level was reached and the filing time. RADAT 33/010/4 translates as follows:

33—The relative humidity at the lowest freezing level was 33 percent.

/—This indicator shows that the lowest level of 0° C. came as the balloon ascended from cold air into warmer air.

010—The height of the lowest level of 0° C. was 1,000 feet MSL.

/4—There were four levels at which the temperature was 0° C.

RADAT ZERO indicates that all portions of the upper air sounding were colder than 0° C.

(8) When radar indications are observed of such importance that they need immediate dissemination the information is included in the remarks section.

An example follows:

As Reported in Remarks	*Translation*
CELL TRW++/++ 220/30 D20 2235 TORNADO RPRTD THIS CELL	Solid area of thunderstorms and very heavy rain showers, increasing rapidly in intensity is located 30 miles southwest of the station and is moving from the southwest at 35 knots. This area is 20 miles in diameter and a tornado was reported within it.

(9) Radiation intensity data. These data are of no direct interest to the pilot.

(10) Notices to Airmen (NOTAMS). NOTAMS are transmitted at the end of all meteorological remarks in the Aviation Weather Report, preceded by the indicator (→) and the station identifier.

REPORTS FROM AUTOMATIC WEATHER STATIONS (AMOS)

Robot weather stations are becoming more numerous as equipment is being improved and made available. Several types of equipment are in use, and the reports from each type are slightly different. Automatic equipment can measure runway visibility or runway visual range (if applicable), temperature and dew point, wind direction and speed, altimeter setting, and the amount of precipitation. The equipment can even transmit the report automatically and provide a printed copy. Additional items not yet reported automatically are ceiling, cloud heights, and cloud amounts; prevailing visibility; present weather; obstructions to vision; sea level pressure; and remarks. These items at present are added by a human observer.

The general format of reports from automatic stations is similar to that of other Aviation Weather Reports. The differences are most easily explained by examples. Notice the following report from a regular station:

XYZ M10⦶120⦶/⊕11/2R–F 293/64/64/3011 G18/039/R27VV11/4

This report from one type of automatic station would appear similar to the following:

XYZ M 10 ⦶ 120⦶ 11/2R–F
293/ 64/ 64/3011/039/001/
R27VV1.3/ / /⊕ G18

The report from the automatic station differs from the regular report as follows:

(1) Blank spaces appear in certain elements, since allowance must be made to accommodate the more complex or lengthy elements that are possible under different weather situations. For instance, in the above example, a blank space appears before the temperature and the dew point so that readings in excess of 99 or below zero (—) can be reported. This wide spacing is most striking in the sky cover elements of the report. Only the two most significant sky cover levels are reported. Other layers are given in remarks (/⊕ in the above example).

(2) There is no space in the format for peak gusts or squall data and, when appropriate, such information appears in remarks (G18 in the example).

(3) A cumulative precipitation amount in inches and hundredths follows the altimeter setting. The "001" in the above example signifies 0.01 inches of precipitation; "154" would represent 1.54 inches.

(4) Runway visibility is reported in miles and tenths instead of in miles and fractions.

This same report would appear in approximately the following format from another type of automatic weather station:

XYZ AMOS / 64/ 64/3011/039/001/
R27VV1.3// M10⦶120⦶/⊕11/2R–F/ 293 G18

In this example, the sky cover group, visibility, weather, and obstruction to vision information appear in remarks, followed by sea level pressure and peak gust data.

Temperature and dew point are reported in a variety of ways from automatic weather stations. For example, a temperature of 102° F. and a dew point of 72° F., appearing in a regular report as 102/72, may appear in automatic station reports as 102/72 or as 02/72. Below zero readings, in regular reports –4/–17, for example, may appear from automatic stations –04/–17 or 96/83. In the latter case, the correct reading is obtained by substracting each value from 100 and prefixing a minus sign. Usually it is obvious when it is necessary to do this.

ABBREVIATED SURFACE WEATHER OBSERVATIONS

Complete surface weather observations are made each hour to serve routine aviation requirements. This section deals with special situations requiring supplementary surface observations.

Special Observations. Major changes in weather conditions which are significant to aviation safety and efficiency require the prompt distribution of special observations. These special reports are transmitted on Service A and usually contain the elements of sky and ceiling, visibility, weather, obstructions to vision, wind, and appropriate remarks.

As ceiling and visibility become poorer and consequently more restrictive to aircraft operations, only slight changes in these elements may require the transmission of special reports. Tornadoes, thunderstorms, hail, freezing precipitation, sleet, and sudden wind and pressure changes require special observations.

An example of a special report and its translation follow:

OKC S 2315 O1GF 2005 VSBY S1/2.

OKC—Station designator for Oklahoma City, Okla.

S—Indicates that this is a special observation.

2315—Time of the observation (GMT) on the 24-hour clock. In local time, this example would be 5:15 p.m., central standard time.

O—Sky is clear.

1—Prevailing visibility is 1 mile.

GF—Obstruction to vision is ground fog.

20—Wind is blowing from 200°.

05—Wind speed is 5 knots.

VSBY S1/2—Visibility in the south quadrant is 1/2 mile.

If, while taking an hourly observation, the observer notes a change in conditions important enough to warrant a special observation, the scheduled observation is transmitted as usual, but with the letter "S" following immediately after the station designator.

Local Extra Observations. These observations are required for local airport services at 15-minute intervals when either the ceiling is 500 feet or less, *or* the visibility is 1 mile or less, provided that there is air traffic in the general area. Local extras are made, in addition, immediately following an aircraft accident or a report of an aircraft in distress. They may also be made in response to special requests. Since these observations are made primarily to serve *local* needs, they are not transmitted over the Service A teletypewriter circuit unless they meet the requirements for a special observation.

Supplementary Aviation Weather Reports. Surface weather observations are made at a number of airports other than those having Weather Bureau or Federal Aviation Agency observers. Such airports normally accommodate air carrier operations, are equipped for instrument approaches, or have other specific requirements for weather observations. At these locations, called "Supplementary Aviation Weather Reporting Stations" (SAWRS), abbreviated aviation weather reports are made by personnel certificated by the Weather Bureau. In most cases, the personnel are airline employees, but airport employees or other cooperators make the reports at some airports. Most SAWRS do not have sending capability on the Service A teletypewriter circuit, so their Supplementary Aviation Weather Reports are filed at irregular intervals with stations which can give them the required distribution.

Individual reports from SAWRS are transmitted without a heading. When two or more reports have a common observation time and the same distribution, they are grouped into a single transmission preceded by a heading containing the designator "SW."

Limited Airport Weather Reports. Some FAA towers or combined station/towers at locations where weather observations are not available through a local source make weather observations in order to discharge properly their air traffic control obligations. Weather observations from this type of station, called a Limited Airport Weather Reporting Station (LAWRS), consist of only those elements considered pertinent to traffic control functions. Since observing the weather is secondary to the control of air traffic, all observational duties are performed within the tower cabs. Temperature and dew point are omitted except when remote reading equipment has been installed. Observations normally are made only during those periods when the information is needed for traffic control purposes. LAWRS observations are distributed on Service A only by those stations where these reports serve to narrow a gap in the observational network.

PILOT WEATHER REPORTS (PIREPS)

Weather observations made from the ground contain precise information that is most valuable for landings and takeoffs, approaches and departures. They do not, however, fully meet the need for information on weather conditions at flight altitude. Heights of upper cloud layers, turbulence, and icing frequently are evident only to the airborne pilot, and his reports of these conditions are valuable to other pilots, controllers, weather briefers, and forecasters.

Air traffic control facilities (towers and centers) make wide use of pilot weather reports to expedite the flow of air traffic both in the terminal and in enroute areas. For example, pilot weather reports of turbulence would be considered when assigning a departure route or flight altitude. Flight Service Stations make extensive use of pilot weather reports in providing preflight briefing and in-flight services to pilots. The reports are broadcast regularly over selected navigational aids for the benefit of listening pilots and are transmitted on Service A and Area B teletypewriter circuits for the benefit of other facilities. Weather Bureau offices use pilot weather reports in briefing pilots and in weather forecasting.

Because of the importance of PIREPS, air traffic controllers and flight service personnel solicit them during aircraft contacts. Under certain conditions, flight service personnel also solicit them during scheduled and unscheduled broadcasts.

INFORMATION IN PIREPS

There are some types of direct meteorological observations that are available only, or primarily, from pilots. Included in these types are:

- Turbulence
- Icing
- Tops of clouds, fog, dust, etc.
- Cloud bases beyond the reach of surface equipment
- Weather conditions between reporting locations, in mountainous regions, etc.
- Weather conditions requiring instrument flight at particular altitudes
- Visibility (forward and air-to-ground) at flight altitudes

In addition, reports obtained from pilots to supplement other sources of data include valuable information on:

- Thunderstorms, hail and lightning
- Precipitation at flight altitudes
- Wind direction and speed at flight altitudes
- Temperatures on climb and at flight altitudes
- Weather radar information from airborne equipment

The above lists are not all-inclusive but are presented to emphasize the importance of obtaining, using, and relaying pilot weather reports.

READING THE PIREP

Service A teletypewriter is the primary means for distributing pilot report information for use by other pilots and weather briefers. Details of the distribution procedures are contained in the Service A Weather Schedules Handbook AT P 7330.2. The order and content of an individual pilot report is as follows:

1. Originating station designator.
2. The contraction PIREP followed by filing time (GMT).
3. Location or extent of condition being reported. (Distances are expressed in nautical miles, except visibility is in statute miles.)
4. Time of pilot's observation (local time).

5. Condition reported.
6. Altitude of condition reported (MSL).
7. Type of aircraft in reports of turbulence, condensation trails, and icing.

Example: At 1629 GMT, a pilot flying a P2V between Richmond, Va., and Washington, D.C., reports to Washington Radio that at 1620 GMT (1120 EST) his aircraft encountered moderate rime ice at 5,000 feet 20 miles south of Washington. This report would be coded:

DCA PIREP 1629 20 S DCA
1120E MDT RIME ICE 50 P2V

Only *urgent* PIREPS (severe or extreme turbulence, moderate or heavy icing, tornadoes, etc.) are transmitted individually during scan periods over Service A. Pilot weather reports of cloud base and cloud top information in a station's local area are included in the "remarks" section of the surface aviation observation (SA).

PILOT WEATHER REPORT SUMMARY (UA)

Every half hour, Flight Service Stations routinely summarize all pilot weather reports received and forward them, via the Area B teletypewriter network, to the appropriate Weather Bureau FAWS center(s). Each hour, the FAWS center summarizes the collection of station PIREP summaries with other PIREPS received into a FAWS area summary (UA). The FAWS area summary is then filed for transmission on Service A during the hourly scan period. Shown below is an example of a FAWS area PIREP summary as it would appear on the Service A teletypewriter network:

DCA UA 061225
LIBERTY DAM-22 NW DCA RW- TO RW 10
HRN 65⦶75 H ABV VSBY S10-15 85
LFI-URB 70⊕80 CAVU ABV. LGT TURBC 70 DC3
30 W ECG MDT TURBC 70 ACFT UNK
EWN-8 N ECG ⦶55 80⦶120 160⊕
NKT-HAT 70⦶85 120⦶160 OAOI 150 OI 80
38 SE RIC SVR TURBC 60 DC3
MYR-DCA OCNL SVR CAT FL280 B707
LBT-FLO IN CLR AT 95 ⦶V⦶ BLO
RDU-ORF 30U70 E150⊕
25 S GVE HVY MXD ICG 60-90
17 ENE DAN-PSK ⦶V⊕65 100⊕ OAT 12C 80
LOZ-BLF U⦶ TIL 50 E BLF 60-70⦶125 140⊕
MGW-10 E FRR 60⦶70. 10-2515/-2. LGT TURBC 100 L188
5 SE PIT ⦶12 50⊕ NO PCPN SMTH 35 C172
35 SE MRB INTMTLY BL MDT TURBC R 60 TURBC INCRS WWD C54
50 E SBY LRG ISLTD TSTM DIAM 25 MOVG EWD CONTUS LTNG ALL TYPES
TOP CB ESTD 400 CIRCUMNAVIGATED TO S

For decoding purposes, you should recall that altitudes are shown in hundreds of feet above MSL, and that horizontal distances are shown in nautical miles. Visibility is always shown in statute miles. Authorized word or phrase contractions, weather symbols with the appropriate intensity indicator (+, —, — —, etc.), and international cloud abbreviations (CB, AC, AS, etc.) are used in pilot weather reports and summaries. If a word or phrase contraction is not available, complete words are used. The letter "U" usually indicates some "unknown" value, for example, intensity (RWU), amount (15U20), or height (U).

The summary shown in the example above is decoded as follows:

This PIREP summary was filed from Washington, D.C., on the 6th day of the month at 1225 GMT.

Liberty Dam to a point two two miles northwest of Washington, light to moderate rain showers at one thousand.

Over Herndon, broken layer, base six thousand five hundred, top seven thousand five hundred; haze above; visibility south is between one zero and one five miles at eight thousand five hundred.

Langley Air Force Base to Urbanna, overcast layer, base seven thousand, top eight thousand; clear or scattered clouds and visibility more than one zero miles above; light turbulence at seven thousand, reported by a DC three.

Three zero miles west of Elizabeth City, moderate turbulence at seven thousand, aircraft type not reported.

New Bern to a point eight miles north of Elizabeth City, broken layer, top five thousand five hundred; higher broken layer, base eight thousand, top one two thousand; overcast layer above, base one six thousand.

Cherry Point to Hatteras, broken layer, base seven thousand, top eight thousand five hundred; higher broken layer, base one two thousand, top one six thousand; on and off instruments at one five thousand; on instruments at eight thousand.

Three eight miles southeast of Richmond, severe turbulence at six thousand, reported by a DC three.

Myrtle Beach to Washington, occasional severe clear air turbulence at flight level two eight thousand, reported by a Boeing seven zero seven.

Lumberton to Florence, in the clear at niner thousand five hundred; scattered variable to broken clouds below.

Raleigh to Norfolk, lower layer (amount unknown), base three thousand, top seven thousand; overcast layer above, base estimated one five thousand.

Two five miles south of Gordonsville, heavy mixed icing, six thousand through niner thousand.

One seven miles east northeast of Danville to Pulaski broken variable to overcast layer, top six thousand five hundred; overcast layer above, base one zero thousand; outside air temperature one two degrees Celsius at eight thousand.

London to Bluefield, broken cirriform, height unknown, until five zero miles east of Bluefield, then broken layer, base six to seven thousand, top one two thousand five hundred; overcast layer above, base one four thousand.

Morgantown to a point one zero miles east of Front Royal, broken layer, base six thousand, top seven thousand; wind at one zero thousand, two five zero degrees, one five; temperature minus two degrees Celsius; light turbulence at one zero thousand, reported by a Lockheed Electra.

Five miles southeast of Pittsburgh, broken layer, top one thousand two hundred; overcast layer above, base five thousand; no precipitation, air smooth at three thousand five hundred, reported by a Cessna one seven two.

Three five miles southeast of Martinsburg, intermittently between layers; moderate turbulence, moderate rain at six thousand; turbulence increases westward, reported by a C five four.

Five zero miles east of Salisbury, large isolated thunderstorm, two five miles in diameter, moving eastward, continuous lightning of all types; top of cumulonimbus cloud estimated four zero thousand; circumnavigated to the south.

WEATHER RADAR OBSERVATIONS (SD)

Weather radar is used primarily for detecting and tracking severe storms such as thunderstorms, tornadoes, and hurricanes. Weather radar equipment used by the Weather Bureau is adjusted to a wavelength that gives the best signal return, considering attenuation, from water droplets and other precipitation particles. The long range radar used by air traffic control facilities employs a wavelength and other devices which minimize the signal return from water droplets and other precipitation particles.

A storm does not actually produce a radar signal. Instead, water droplets reflect transmitted radio waves and produce "echoes" which are depicted on the radar scope. The strength of these echoes is evaluated to determine intensity. The size and number of water droplets, as well as the distance to the storm, determine the strength of the return signal (echo).

Echoes that are classified as "heavy" or "very heavy" in intensity usually indicate a storm with severe or extreme turbulence, hail, and heavy icing conditions. Echoes of a "light" or "very light" intensity are indicative of snow, light rain, or possibly very heavy drizzle. The strength of the echoes is evaluated by the Weather Bureau specialist who makes the observation. The Radar Meteorologist correlates the radar presentation with surface reports, pilot reports, and the synoptic situation as part of his evaluation.

Two basic formats are used in the distribution of weather radar information to the users. One format, identified as "SD," is used for an individual radar report, while the other format, identified as "SD–1," is used for a composite summary of all the simultaneous individual radar reports in the contiguous States.

INDIVIDUAL RADAR REPORTS (SD)

Radar reports originate mainly from Weather

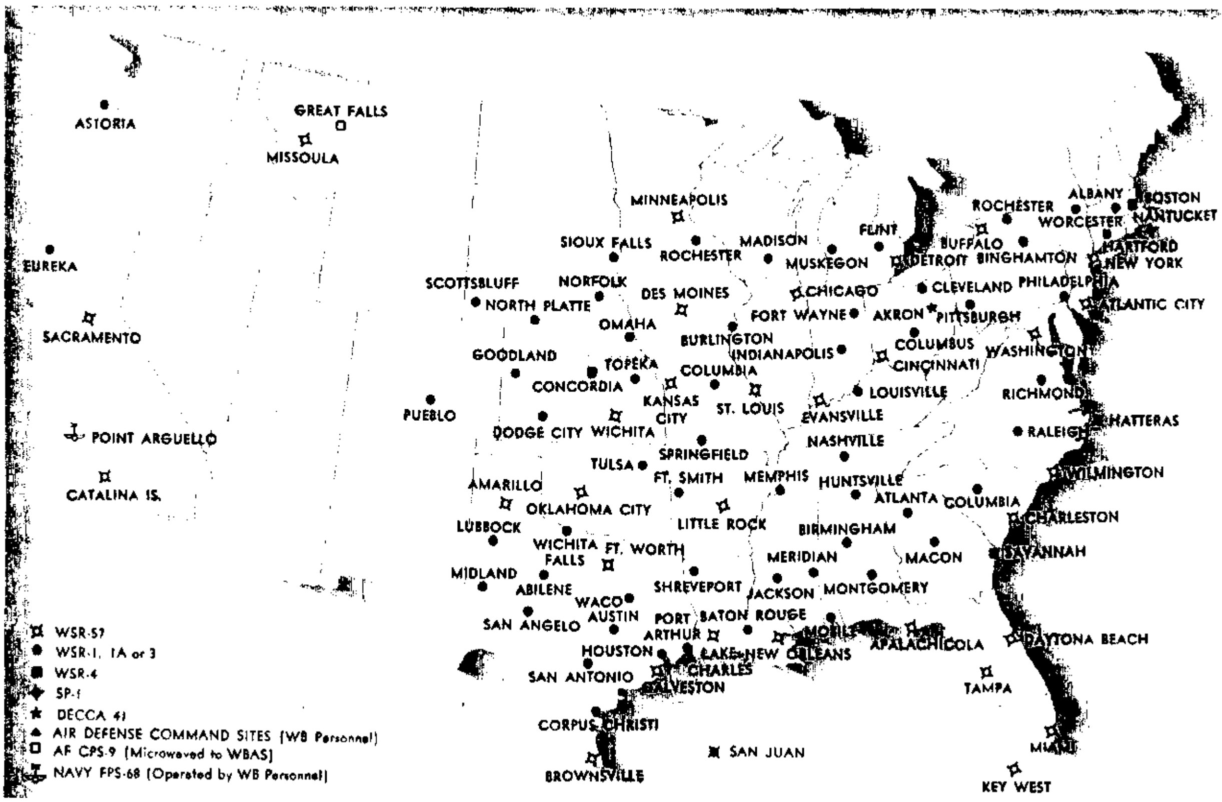


FIGURE 142. Radar reporting network.

Bureau stations, but are supplemented by reports from military radar. The most effective weather radar in use today is the WSR–57 (Weather Surveillance Radar) operated by the Weather Bureau. Having a range of 250 nautical miles, WSR–57 radars are strategically placed for surveillance of most of the United States east of the Rocky Mountains, since this is the area where severe storms are most frequent. Figure 142 shows the locations and types of weather radar in the contiguous States.

Radar reports are made hourly by all WSR–57-equipped stations at H+45. These reports are called "RAREPS." (Weather radar stations equipped with other type radar, such as the WSR–1, also make record observations at H+45, but this schedule is not routine for those stations within 100 nautical miles of a WSR–57-equipped station.) Special radar reports are made hourly at H+15 and at any other time when important echo patterns are observed. If a radar report is a "special," the term "SPL" and time (GMT) of the radar observation are inserted following the radar station identifier. Service A transmission of individual radar reports contains a time group (GMT) for all record as well as special observations.

The individual radar report is composed of certain data arranged in the following manner:

a. Location identifier.

b. The contraction "SPL" if the report is a special. (If the report is not a special, this contraction is omitted.)

c. The contraction "SD" meaning storm detection (omitted in sequence collections).

d. Time of the report (GMT) (omitted in sequence collections).

e. Character of echoes.

f. Weather and intensity.

g. Intensity tendency.

h. Location and dimension of echoes.

i. Movement.

j. Altitude of bases and/or tops of echoes.

k. Remarks and unusual echo formations.

a. *Location Identifier.* This is a three letter group identifying the station which makes the radar report.

b. c. (Explained above.)

d. *Time of Report.* Time of the observation (if given) is in Greenwich mean time. The time is always included for special observations or any report transmitted on Service A. If the time is omitted, this means it is a record observation taken at H+45.

e. *Character of Echoes.* The character of echoes includes coverage, shape (area, line, cell), and difference between precipitation reaching the ground and that not reaching the ground. The echo patterns are classified as a line only if the echoes are arranged in recognizable or organized lines such as might be reflected from a squall line or front. Spiral band areas are reported mainly with storms of tropical origin. If echoes are persisting, that fact is indicated in remarks. The contractions and symbols used to indicate the character of echoes in the radar report are shown below:

Contraction	Character	Definition
CELL	Isolated Echo	Isolated solid mass of echo.
AREA WDLY ⦶	Widely scattered area	An area less than 1/10 covered with echoes.
AREA ⦶	Scattered area	An area 1/10 to 5/10 covered with echoes.
AREA ⦷	Broken area	An area 6/10 to 9/10 covered with echoes.
AREA ⊕	Solid area	An area solidly covered with echoes.
LN WDLY ⦶	Line of widely scattered echoes	A line less than 1/10 covered with echoes.
LN ⦶	Line of scattered echoes	A line 1/10 to 5/10 covered with echoes.
LN ⦷	Line of broken echoes	A line 6/10 to 9/10 covered with echoes.
LN ⊕	Solid line of echoes	A line solidly covered with echoes.
SPRL BAND AREA ⦶ or ⦷.	Spiral band	Curved lines of echoes which occur in connection with a hurricane (includes the wall cloud).
PRSTS-HRS	Persisting echo	An echo of moderate or greater intensity which has moved very little or none during past 1 or more hours.
LYR ⦶, ⦷ or ⊕	Layer Aloft	Echo from precipitation layer not reaching the ground.

f. *Weather and Intensity.* The types of precipitation associated with radar echoes are given by the same symbols used for surface weather reports, i.e., R for rain, S for snow, etc. The intensity of precipitation is denoted by plus (+) and minus (—) signs following the precipitation symbols. For example, — — means *very light,* — means *light,* + means *heavy,* ++ means *very heavy,* the absence of a sign means *moderate,* and U means *intensity unknown.*

g. *Intensity Tendency.* The intensity tendency of the precipitation is indicated by plus or minus signs, unless there is no change or new echoes have formed. These symbols follow the intensity symbols and are separated from them by a slant bar. The following symbols and/or contractions are used to indicate intensity tendency or new cells:

— Decreasing
— — Decreasing slowly
— + Decreasing rapidly
NC No change
\+ Increasing
\+ — Increasing slowly
\+ + Increasing rapidly
NEW New echo (es)

h. *Location and Dimension of Echoes.* Locations of echoes are relative to the radar station. The azimuth (degrees true) is given in three digits followed by the distance (range in nautical miles). The azimuth is separated from the distance by a slant bar. Thus, the group 316/83 would mean 316° true and 83 nautical miles.

If the echoes are arranged in a straight line, the azimuth and distance to the ends of the line will be given. If the echoes are arranged in a curved line, or in spiral bands, the azimuth and distance will be given to as many points on the longitudinal center of the line, or bands, as necessary to establish the shape of the line or spiral bands. If an irregular shaped area is covered by echoes, the perimeter of the echoes will be reported as necessary to outline generally the contour of the clearcut echo area. If a single echo, such as a thunderstorm cell, or an area of echoes of roughly circular shape is observed, the azimuth and range to the center of the cell or area will be reported.

The dimensions of echoes are given as width (W) or diameter (D) in nautical miles. For example, 50W means 50 nautical miles wide and D20 means 20 nautical miles in diameter. Mean width of lines or spiral bands and mean diameters of cells or roughly circular areas are reported. The terms AVG W or AVG D are used for *average width* and *average diameter* respectively.

i. *Movement.* The direction of movement of echoes is indicated in tens of degrees and speed is indicated in knots. To indicate the movement of individual cells within an area of echoes, the word CELLS or ELEMENTS precedes the movement symbols, i.e., CELLS 2720. The movement of an area or line of echoes is indicated in the same manner except that the word "CELLS" or "ELEMENTS" is deleted. Line movement is reported perpendicular to its axis.

j. *Height.* Height of echo tops is given in hundreds of feet above mean sea level. The word "TOP" precedes the height indicator. Thus, TOP 400, indicates the top of the echo is 40,000 feet MSL.

k. *Remarks and Unusual Echo Formations.* Certain types of severe storms produce distinctive patterns on the radar scope. For example, the hook-shaped echo often is associated with tornadoes, and the spiral bands are associated with hurricanes. The melting level is sometimes reported if the radar observer sees an intensified radar signal a short distance below the freezing level. If hail, strong winds, and other weather phenomena are known to be associated with identified echoes on the radar scope, the location and type of phenomena are given in remarks.

OPERATIONAL STATUS

When a complete radar report is missing, the reason is given following the station identifier and replaces the usual coded report, for example:

OKC PPINE

Contractions used to indicate the reason for a missing report are given below:

PPINE—No echoes observed.

PPIOM—Equipment inoperative for maintenance.

PPINO—Equipment inoperative due to breakdown.

PPIOK—Equipment operation resumed.

PPINA—No observation taken.

RHINO—Range height indicator not operating on scan; echo height information not available.

ARNO—A-scope or A/R indicator is not operating.

ROBEPS—Radar equipment is operating below performance standards.

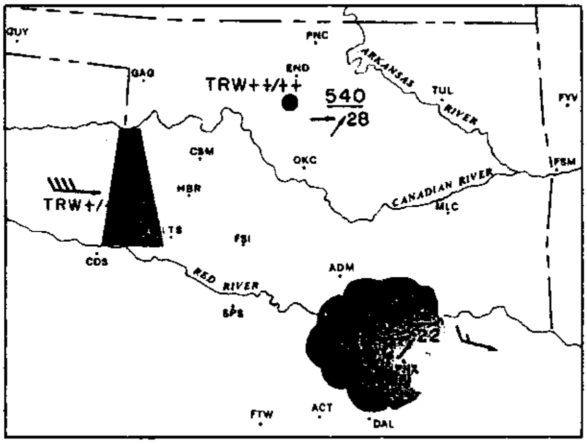


FIGURE 143. Diagrammed radar report.

SCHEMATIC DIAGRAM

Figure 143 shows a schematic diagram prepared from a radar report. After a radar report has been plotted on a chart, useful plain language statements can be obtained as shown below:

At 1515 CST, radar shows the following echoes: solid line of thunderstorms with heavy rain showers, increasing in intensity. This line is located in extreme western Oklahoma along the Texas-Oklahoma border from the Canadian River southward to the Red River. This line varies in width from 10 miles at the north end to 40 miles at the south end. It is moving eastward at 40 knots with maximum echo tops of 50,000 feet at the south end in extreme southwestern Oklahoma between Altus and Childress, Tex.

In north central Oklahoma, a thunderstorm with very heavy rain showers is centered 10 miles south of Enid. It is moving east-northeast-

ard at 28 knots, and increasing rapidly in in-
ensity. This thunderstorm is 8 miles in diame-
er with tops 54,000 feet. Hail 1 inch in diame-
er has been reported with this echo.

In north-central Texas and extreme south-
entral Oklahoma, radar shows a newly devel-
oped area of scattered light rain showers within
a 40-mile radius of the Sherman-Denison area.
Tops 20,000 feet. This area is moving eastward
at 15 knots. Individual showers average 5 miles
n diameter and are moving northeastward at 22
knots.

RADAR REPORT SUMMARY (SD-1)

A summary of radar observations is prepared by the weather radar analysis unit at Kansas City, Mo. (MKC) and entered hourly on Service A. A radar summary in teletypewriter form usually contains the following information:

A heading which includes the originating location for the summary (MKC); the identifying letters "SD-1" for storm detection; and a six-figure date-time group (GMT) for the transmission time.

The observation time which is 45 minutes past each hour. (Note that the transmission time of the summary is 55 minutes after the observation time.)

The summary report describing the configuration of the radar echo pattern. Intensity is given as very light (— —), light (—), moderate (no symbol), heavy (+), and very heavy (++). The type of precipitation (occurring either at the surface or aloft) identified with the echoes is given using standard teletypewriter symbols. The echo pattern location is described in terms of distance (nautical miles) and direction (true) from well known locations. Maximum height of echo tops is given in hundreds of feet (MSL); e.g., 600 is 60,000 feet. Movement of echoes or groups of echoes is indicated in the same manner that wind is reported. 1810 means that the echo, line, or area is moving from the south at 10 knots. When individual echo movement is shown, the term "CELLS" or "ELEMENTS" precedes the movement symbols.

A forecast on expected movement and changes in intensity for the next few hours. This section appears every three hours at 0040 GMT, 0340 GMT, etc.

Shown below is an example of a Radar Report Summary:

MKC SD-1 022140
2045 DATA

PLAINS AND WRN GLF
AREA BRKN R-RW- BNDD 30 NNE ALO 10
N ICT 50 E OKC 30 N MWL 25 S CVS 25
NW GUY NERN PTN WDLY SCTD TOPS
120 CNTRL AND SRN PTN TOPS 200 2315
LN BRKN RW- DCRG SLOLY 15 WIDE 30 W
TUL 20 W GGG 40 SSW PSN 2715

AREA SCTD RW- 50 WIDE 60 SE GSW 30
ENE BWD TOP 160 2215
AREA SCTD RW- 150 WIDE 25 E GGG 140 S
BRO TOPS 200 2715 WITH LN SLD TRW 20
WIDE 30 SW LFK 15 W HOU 60 E CRP
TOPS 330 TRW+INCRG SLOLY 15 SW HOU
TOP 500
AREA BRKN RW INCRG 75 DIAM 90 SE
CLF MAX TOPS 350 1810

FCST
ALL ECHOES EXCP FOR LN ERN TEX WL
DCR IN INTENSITY AND COVERAGE IN
TWO TO THREE HRS. LN TRW ERN
TEX WL CONT EWD WITH NO CHG
INTENSITY NEXT THREE HRS

The above summary covers the Plains and Western Gulf States. It is read as: Broken area of light rain and light rain showers, showing no change in intensity, bounded 30 (nautical) miles north-northeast of Waterloo (Iowa), 10 miles north of Wichita (Kansas), 50 miles east of Oklahoma City (Oklahoma), 30 miles north of Mineral Wells (Texas), 25 miles south of Clovis (New Mexico) to 25 miles northwest of Guymon (Oklahoma). Northeastern portion widely scattered with tops at 12,000 (feet MSL). Tops central and southern portion 20,000 feet. Area is moving from 230° at 15 knots.

Broken line of light rain showers, decreasing slowly in intensity, 15 miles wide located from 30 miles west of Tulsa (Oklahoma) to 20 miles west of Longview (Texas) to 40 miles south-southwest of Palestine (Texas). The line is moving from 270° at 15 knots.

Scattered area of light rain showers, with no change of intensity, 50 miles wide located 60 miles southeast of Greater Southwest International Airport (Texas) to 30 miles east-northeast of Brownwood (Texas) with tops to 16,000 feet. The area is moving from 220° at 15 knots.

Scattered area of light rain showers, showing no change in intensity, 150 miles wide located from 25 miles east of Longview (Texas) to 140 miles south of Brownsville (Texas), tops to 20,000 feet. The area is moving from 270° at 15 knots and contains a solid line of thunderstorms and moderate rain showers, showing no change in intensity, 20 miles wide located from 30 miles southwest of Lufkin (Texas) to 15 miles west of Houston (Texas) to 60 miles east of Corpus Christi (Texas), with tops to 33,000 feet. A thunderstorm with heavy rain showers, increasing slowly in intensity, is located 15 miles southwest of Houston (Texas) with tops to 50,000 feet.

Broken area of moderate rain showers, increasing in intensity, 75 miles in diameter centered 90 miles southeast of Clifton (Texas). Maximum tops 35,000 feet. The area is moving from 180° at 10 knots.

Forecast. All echoes except for the line in eastern Texas will decrease in intensity and coverage in 2 to 3 hours. The line of thunderstorms and moderate rain showers in eastern Texas will continue eastward with no change in intensity during the next 3 hours.

UPPER AIR OBSERVATIONS

Although long-range weather radar probes a considerable portion of the atmosphère, observations of the upper air, used before radar was developed to its present capability, have retained the title of "Upper Air Observations." Actually, all observations other than those made at the ground could fall under this heading. But, in the weatherman's terminology, upper air observations consist of measurements of wind, temperature, pressure, and humidity. When made from aircraft or satellites, these upper air observations are referred to individually.

Other than a few experimental meteorological rocket soundings, there are two types of upper air observations made in the United States. One type, called "Rawinsondes," provides information on wind, temperature, pressure and humidity conditions to very high levels, often above 100,000 feet. Rawinsonde observations are made each 12 hours (0000 and 1200 GMT) at about 70 locations, and each 6 hours at two additional locations in the contiguous United States (see fig. 144). These soundings are made by sending aloft a balloon carrying miniature weather instruments and radio gear (contained in a box). The ascending radio transmits a signal which is received by an automatic tracking instrument on the ground known as a "radiotheodolite." A theodolite is an instrument which measures both vertical and horizontal angles.

At 0600 and 1800 GMT, the RAWIN-only portion of the sounding (winds aloft) is made at 17 of the 70 rawinsonde stations. The remainder of these stations make the other type of winds aloft observations, namely, pilot balloon observations (PIBALS). In addition to these, there are about 80 other stations which make winds aloft observations four times daily (0000, 0600, 1200, and 1800 GMT), using only pilot balloons (PIBALS). This brings the number of locations in the upper-air observational network over the contiguous United States to about 150. In the case of PIBALS, the balloon must be tracked manually, using a theodolite equipped with a telescope. The RAWIN method usually yields soundings to much greater heights because it does not depend on eyesight. In the case of PIBALS, the height to which wind information may be obtained is limited by the presence of clouds.

Upper air observations have increased man's knowledge of the atmosphere, and fresh information obtained from them is very valuable to the forecaster predicting future wind and weather conditions. They are most valuable when plotted on an area chart and viewed as a group. Individual reports may then be better evaluated in space and time, and the state of the atmosphere and its changes can be determined more systematically.

Upper wind observations are charted at the National Meteorological Center and transmitted via facsimile to field offices for direct use by pilots, weathermen, and others. Temperature,

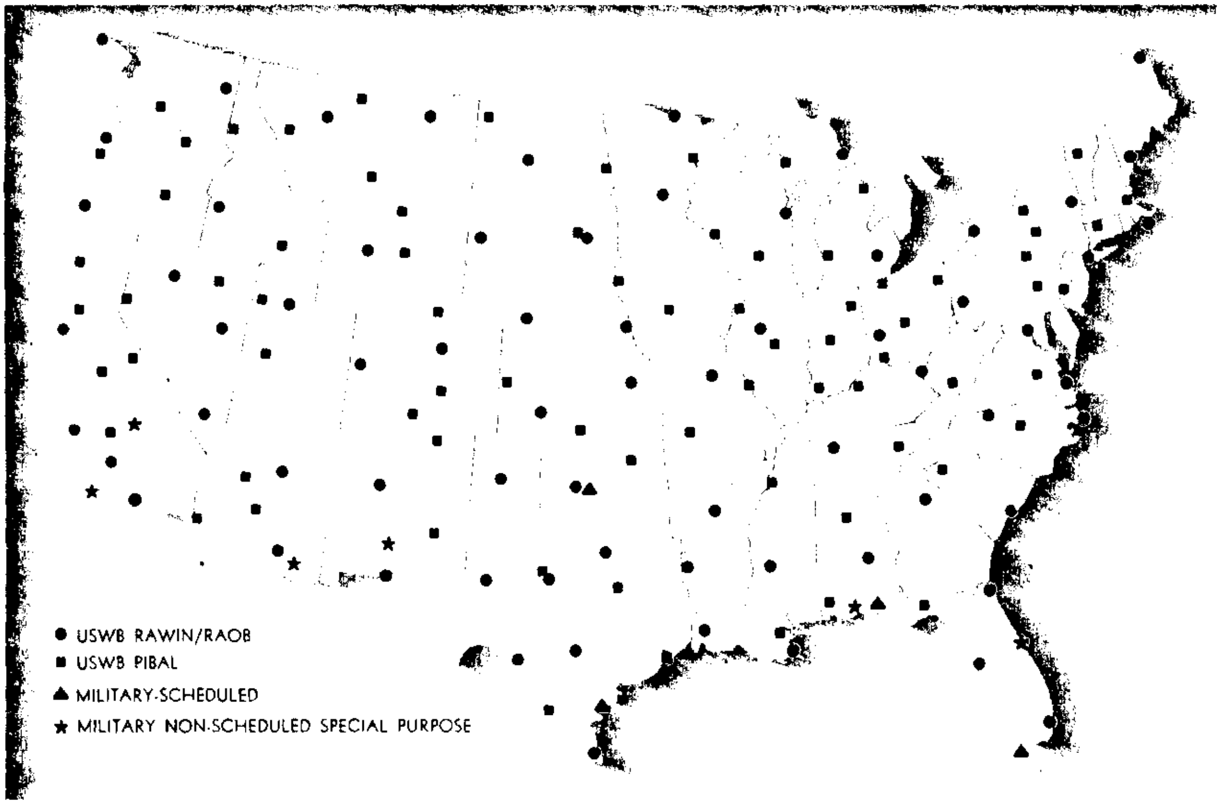


FIGURE 144. Synoptic upper air observation sites.

pressure, and humidity data must be analyzed before distribution in chart form. Weather charts are discussed in the next chapter.

The pilot is encouraged to use the plotted winds aloft charts and winds aloft forecasts (see ch. 17) in his flight planning. It is not necessary for him to translate the coded individual upper air observations which primarily are intended for charting and analysis by forecast centers.

Chapter 16
WEATHER CHARTS

Weather charts have been a tool of the forecaster for many years. They also are used by the general public in the form of the Weather Bureau's "Daily Weather Map," the weather charts in most newspapers, and the "props" used by the TV weatherman.

Until 15 years ago, operational charts of atmospheric conditions aloft generally did not extend above 15,000 feet. The higher reaches of the troposphere still were much of a mystery. Forecasts were prepared on the basis of analyses of weather conditions observed at and relatively close to the earth's surface. The search for weather clues has extended to higher and higher levels, necessitated not only by the increasing altitude capability of aircraft, but also because weather causes often are not revealed except at high altitudes.

With the increasing altitude capability of rawinsondes and with rocket soundings and other space vehicles, man continues to probe the atmosphere farther and farther away from the earth. Charting of conditions at higher altitudes immediately follows the availability of sufficient data to make analyses possible, and *research* charts for levels up to 180,000 feet are prepared routinely.

For many years, weather charts were "unfathomable" to the public. Although such charts are still in use, public interest, stimulated largely by television, has made the "unfathomable" more fathomable. Also, weather charts in a form more usable by the pilot and others have been developed in recent years. Among these charts are:

- Radar Summary
- Weather Depiction
- Cloud and Precipitation Forecasts
- High Level Significant Weather Forecasts
- Stability Index
- Winds Aloft
- Severe Weather Outlook
- Temperature Change Forecasts
- Quantitative Precipitation Forecasts

Prior to the facsimile system as a method of distribution of weather information, usually the only graphic materials available at local weather offices were surface charts, charts of conditions at about 10,000 feet, and a few adiabatic diagrams. Now a wide variety of graphic material for use by weathermen, pilots, and many others is available.

This chapter emphasizes those weather charts which are *most* useful to the pilot. Omission of certain other weather charts is not intended to imply that they have no usefulness. The following paragraphs cover those charts displayed in a typical weather station.

WEATHER DEPICTION CHARTS

The Weather Depiction Chart is one of the most valuable graphic displays of weather. It gives the pilot information which directly affects his flight plan decision-making. The chart consists of plotted and analyzed data on cloud heights and visibility across the contiguous States and southern Canada. The plotted data include:

- Precipitation and/or other important weather phenomena
- Sky coverage
- Visibility (when 6 miles or less)
- Cloud base (in hundreds of feet above the ground up to 20,000 feet)

The analysis consists of:

- Solid lines enclosing areas where ceilings are below 1,000 feet and/or visibilities are below 3 miles. (Enclosed areas usually are shaded in red by the local weather station.)
- Scalloped lines enclosing areas where ceilings are below 5,000 feet but not below 1,000 feet and visibilities are greater than 3 miles. (These areas usually are shaded in blue locally.)

Thus, areas where flights must be conducted under Instrument Flight Rules are immediately apparent as well as those areas which bear watching for possible worsening conditions (see fig. 145).

Weather Depiction Charts are prepared every three hours beginning with data observed at 0100 GMT (Z). Since data at a minimum are 1⅓ hours old by the time the chart reaches the local weather station, latest Aviation Weather Reports should be consulted in order to update the information on the Weather Depiction Chart. Another reason for checking further is that, although the analysis is based on all data available at the National Meteorological Center, there may be information available locally which indicates that conditions between reporting stations actually are different from those depicted on the Weather Depiction Chart, especially where weather is quite variable.

Air Force pilots use graphic forecasts known as "Horizontal Weather Depiction (HWD) Charts" to support long flights, particularly over water. HWD charts should not be confused with the Weather Depiction Charts of the Weather Bureau which are based on *observed* data only. HWD charts basically are individual trip forecasts, and they are not given general distribution.

Designed to give the pilot a "plan view" of a weather situation, the Weather Depiction Chart is used most effectively in conjunction with the surface weather chart, which often indicates the causes of cloud formations and/or restrictions to visibility.

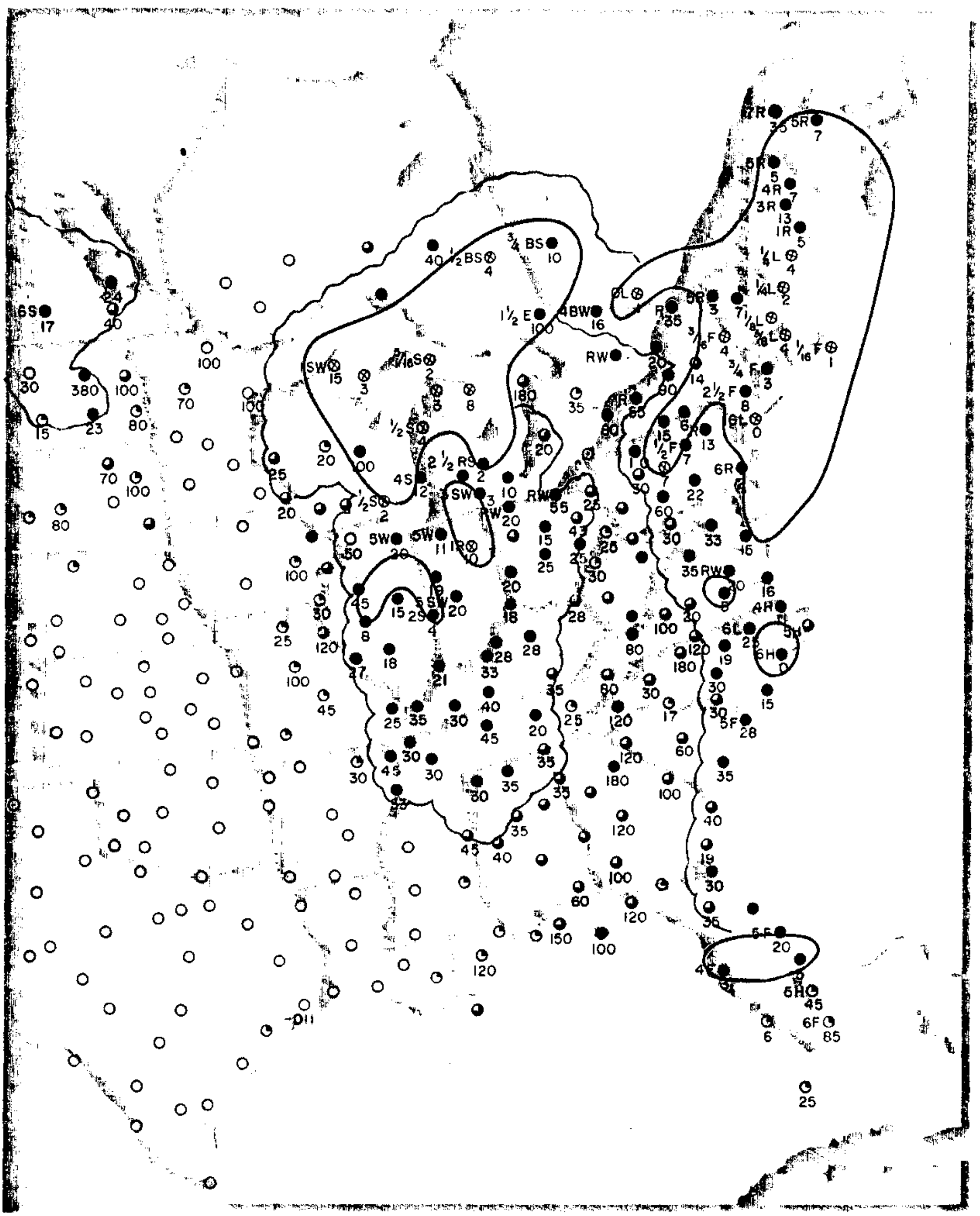


FIGURE 145. Weather depiction chart, 1300 GMT, March 5, 1964.

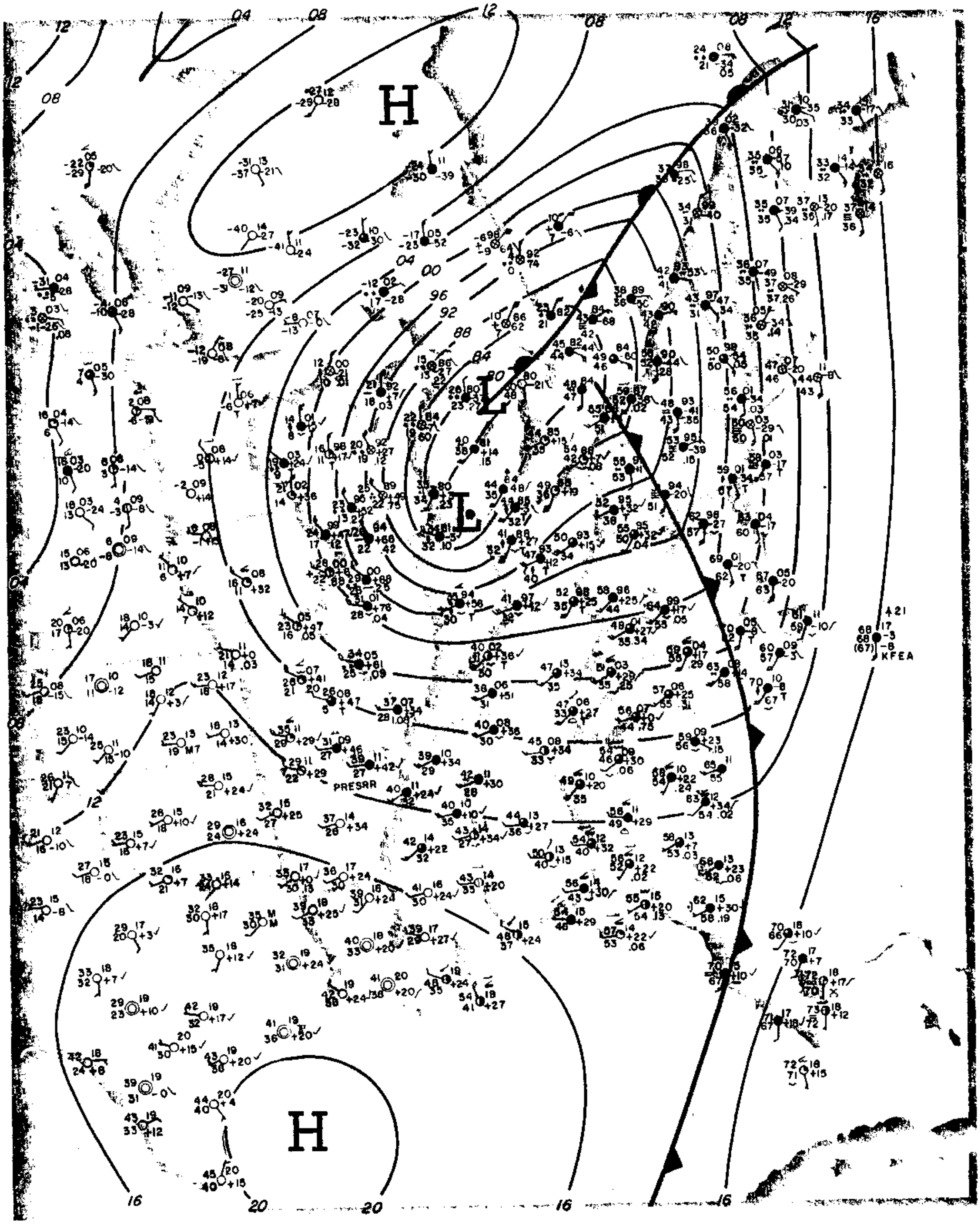


FIGURE 146. Surface weather chart, 1200 GMT, March 5, 1964.

SURFACE WEATHER CHARTS

In addition to plotted data, the surface weather chart provides an analysis of pressure patterns at mean sea level and the surface locations of fronts. (The depiction of fronts was given in ch. 10.) Figure 146 is an example of a surface weather chart distributed from NMC.

After recognizing basic weather symbols (fig. 130), the pilot should concentrate on pressure patterns and fronts more than on plotted data on the surface chart. More up-to-date weather data are available through the Aviation Weather Reports. The observational data on surface charts is included primarily for weathermen. Since it is about 2 hours old by the time the chart reaches the field office, it may be more misleading than helpful for pilots.

Surface weather charts for an area including the 48 contiguous States are distributed every 3 hours beginning at 0000 GMT. Surface charts of the entire Northern Hemisphere are prepared every 12 hours. Comparison of the current surface weather chart with earlier ones gives the pilot a first approximation of how weather systems are progressing. However, it is not safe to assume that they will continue to progress in the same fashion, and the pilot is not briefed (self-briefed or otherwise) until he is thoroughly familiar with weather conditions forecast for his route and his planned destination. (If the forecast weather for his planned destination is poor, he should have an alternate destination.) Chapter 18 discusses the content of briefings more completely.

CONSTANT PRESSURE CHARTS (OBSERVED)

Constant Pressure Charts are used in conjunction with surface weather charts to find what *past* conditions were in the atmosphere, such as the speed and direction of wind; temperatures and freezing levels; the intensity, speed, and direction of movement of frontal and pressure systems; the amount, type, and intensity of cloud formations and precipitation areas; and areas of icing, turbulence, and thunderstorms.

Constant Pressure Charts, together with surface weather charts and other charts and diagrams, present a three-dimensional picture of the atmosphere. The standard pressure surfaces for which these charts are prepared and transmitted by facsimile are listed below with their corresponding approximate altitudes:

Standard pressure surface (Millibars)	*Approximate height above mean sea level (Meters)*	*(Feet)*
1,000	120	400
850	1,500	5,000
700	3,000	10,000
500	5,500	18,000
300	9,000	30,000
200	12,000	39,000
100	16,000	53,000

With the exceptions of the 1,000-millibar (mb.) and the 100-mb. Charts which are transmitted once daily, the charts listed above, based on data observed at 0000 and 1200 GMT, are transmitted twice a day.

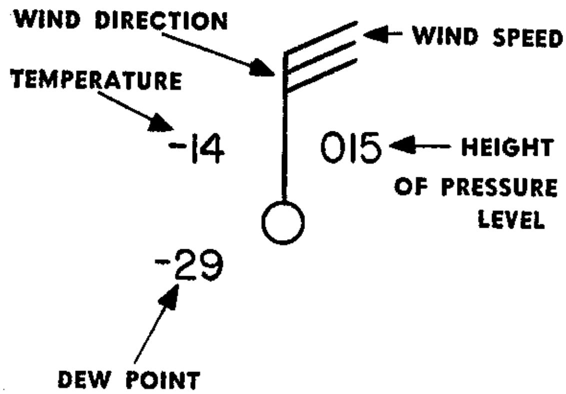


FIGURE 147. Plotting model used on constant pressure charts.

CONTENT OF CONSTANT PRESSURE CHARTS

The plotting model used on constant pressure charts is shown in figure 147. Further explanatory notes follow:

- *Wind direction* is plotted to the nearest 10°. *Wind speed* is plotted to the nearest 5 knots.

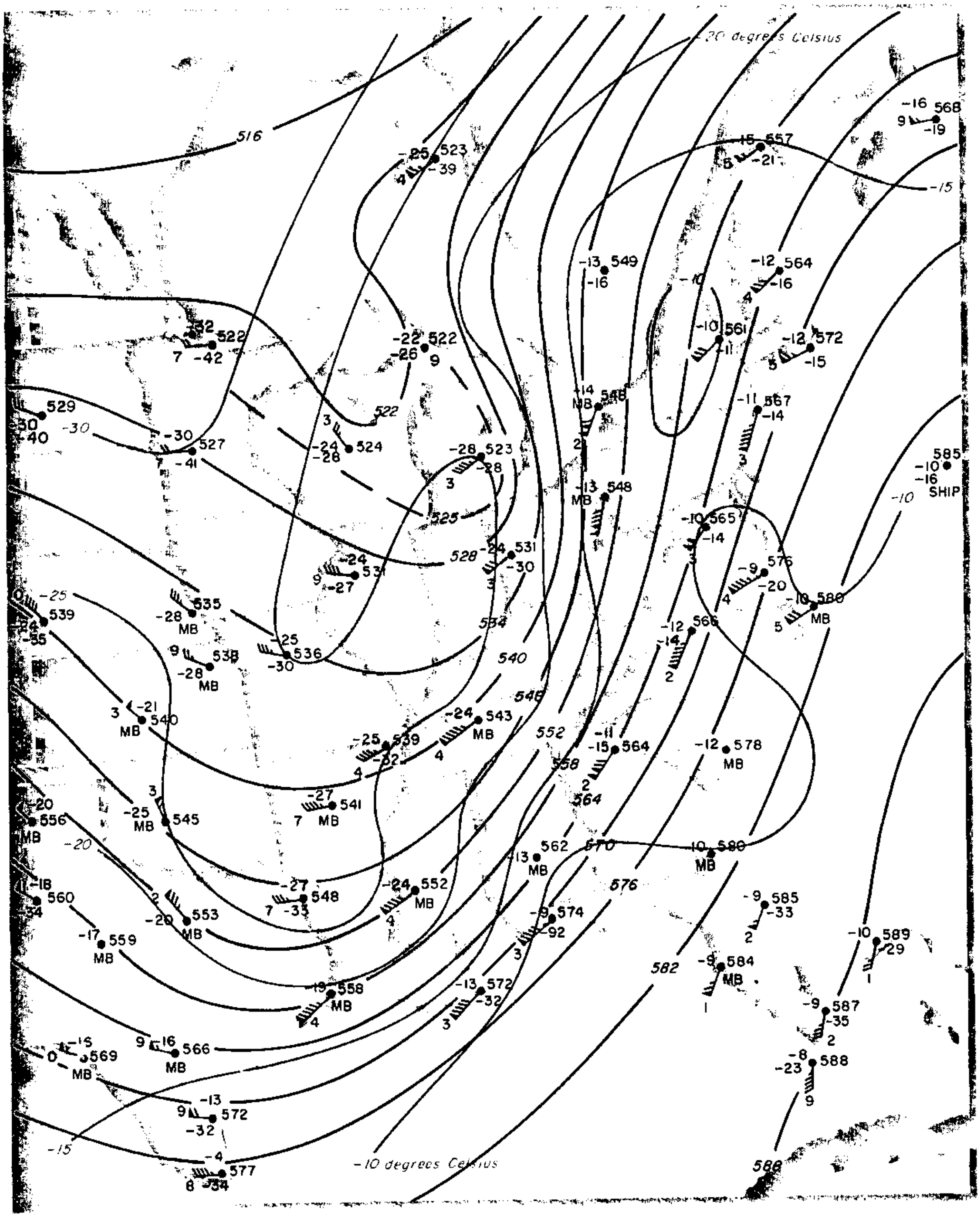


FIGURE 148. 500 millibar chart, 1200 GMT, March 5, 1964.

A half barb on the wind shaft ( ) represents 5 knots, a full barb ( ) 10 knots, and a pennant ( ) 50 knots. The wind blows in the direction from the barb or pennant to the station. For example, a wind of 85 knots from 270 degrees would be plotted as 7 . The "7" plotted to the left of the pennant is the middle digit of the wind direction (270° in the example) and is added in order that there can be no doubt about the reported direction of the wind.

- *Wind data* observed *immediately at the height* of the pressure surface which the chart represents is plotted as shown in this example of a 40-knot wind from due west: 7 . If the wind is for a level *near* but not immediately at the height of the pressure surface, the wind barbs are broken and would appear as:

  7 .
  (16)

  The "16" in parentheses under the station circle signifies the thousand-foot level of the plotted wind—in this example, 16,000 feet.
- The *height* plotted at the station circle is the elevation at which the sounding instrument, released from that particular station, reached the pressure surface that the chart represents. Heights are plotted on the 850 mb. and 700 mb. charts in meters with the first digit of the whole value omitted. A plotted height of 503 on the 850-mb. chart, for example, represents a height of 1,503 meters. Heights on the charts at the 500-mb. surface and higher are plotted in decameters (tens of meters), and a zero must be added to obtain the whole value. On the 200-mb. and 100-mb. charts, the first digit (always 1) also is omitted. For example, a plotted height of 209 on the 200-mb. chart represents a height of 12,090 meters.
- *Station circles* on the 850-mb. and 700-mb. charts are shaded at stations where the spread between the temperature and dew point at the height of the pressure surface is 5° C. or less. At and above the 500-mb. surface, all station circles are shaded because this makes location of stations easier. This point is emphasized because many pilots know that the symbol in the station circle on *surface* weather charts does indicate the amount of total sky cover, complete shading of the circle signifying an overcast sky. However, the shading of station circles on constant pressure charts is not related to the amount of sky cover.
- *Temperature and dew point* are plotted to the nearest whole degree Celsius (centigrade).

DESCRIPTION OF ANALYTICAL FEATURES

The various lines which appear on Constant Pressure Charts represent the following information:

- *Solid (Unbroken) Lines* are lines of equal heights, often referred to as "contours." They are drawn for intervals of 60 meters on charts below the 300-mb. surface, and for intervals of 120 meters on the 300-, 200-, and 100-mb. charts. The height lines may be used in the same way as isobars on surface weather charts. Above the effects of friction, the wind blows generally parallel to the height lines, and wind speeds increase as the spacing between the height lines decreases.
- *Broken Lines With Long Dashes,* also lines of equal heights, sometimes are drawn for intermediate intervals (every 30 meters below 300 mb.) in order to provide better definition of the hills and valleys of pressure.
- *Short Dashed Lines* usually are "isotherms" (lines connecting points of equal temperature). They normally are drawn for 5° C. intervals. Many local weather offices color isotherms in "red" for easy identification.
- *Dotted Lines* are "isotachs" (lines connecting points of equal wind speeds regardless of wind directions). Isotachs are drawn only on the 300-, 200-, and 100-mb. charts. Intervals are *25* knots for wind speeds up to 150 knots and *50* knots for speeds above 150 knots.
- *A Heavy Broken Line With Arrowheads* indicates an "axis of maximum wind," often referred to as an "axis of the jet stream." These are indicated only on the 300-, 200-, and 100-mb. charts, except that once a day the axes of maximum wind at the 500-mb. surface are transmitted in a chart projection which covers most of the Northern Hemisphere.

Figure 148 shows a chart of the 500-mb. surface.

FIGURE 149. Winds aloft chart (observed) for 10,000 feet, 1200 GMT, March 5, 1964.

WINDS ALOFT CHARTS

NMC plots and transmits wind data obtained from rawin and pilot balloon (PIBAL) observations (made at 0000, 0600, 1200, and 1800 GMT), using the same barb and pennant system found on surface and constant pressure charts. Three sets of winds aloft charts are transmitted, each set containing four small charts for selected altitudes (above MSL) as follows:

LOWER LEVELS: second level above the surface; 5,000; 8,000; and 10,000 feet.

INTERMEDIATE LEVELS: 14,000; 20,000; 25,000; and 30,000 feet.

UPPER LEVELS: 35,000; 40,000; 50,000; and 60,000 feet.

The height and temperature of the tropopause are plotted for each station on the 0000 GMT (Z) and 1200 GMT winds aloft charts for 35,000 feet.

Some of the above levels are near those of standard constant pressure surfaces (see table on p. 188), while the others are for levels between standard pressure surfaces. Winds aloft charts, therefore, are supplements to constant pressure charts because, not only are new data transmitted four times a day (contrasted to twice a day in the case of constant pressure charts), but also data for more altitudes are made available.

REMEMBER: the winds plotted in shafts, barbs, and pennants on charts are *observed* winds—not forecast winds. They can be up to *9 hours old.* However, these wind charts, in conjunction with Winds Aloft Forecasts (see ch. 17), are very important in safe flight planning; expected winds aloft must be considered in computing correct headings, best flight altitudes, the range of the aircraft, ground speed, and estimated time enroute. Flight planning without Winds Aloft Forecasts is inadvisable.

Figure 149 shows a Winds Aloft Chart for an altitude of 10,000 feet MSL. It would be one of four levels represented in a single facsimile transmission.

RADAR SUMMARY CHARTS

Radar Summary Charts are prepared every three hours from all radar observations (RAREPS) (see ch. 15) in the contiguous States and are transmitted by facsimile (see fig. 150). If an aviation severe weather warning (WW) (discussed in ch. 17) is in effect for any area in the contiguous States, the area is outlined by dotted black lines on the Radar Summary Chart. The identification numbers of WW's and their valid times are shown in the lower left corner of the chart.

PROGNOSTIC SURFACE AND PROGNOSTIC CONSTANT PRESSURE CHARTS

Prognostic charts for periods ranging from 12 hours to 3 days in the future are transmitted for the pressure surfaces covered by observed charts with these exceptions: (1) no prognostic chart is prepared for the 100-mb. surface, and (2) prognoses of surface charts are used in lieu of 1,000-mb. Prognostic Charts.

Prognostic surface and constant pressure charts generally resemble their corresponding observed charts, but they have fewer lines and, thus, do not appear as complex (see figs. 151–152). An important difference is that pressure systems and fronts are indicated on prognostic charts as they are *expected* to appear at some future time. Prognostic charts *emphasize* expected frontal positions at the surface and circulation patterns at various levels.

Used in combination with observed surface and constant pressure charts, prognostic charts aid in visualizing expected movement and changes in configuration and intensity of pressure systems and fronts. Forecast positions of

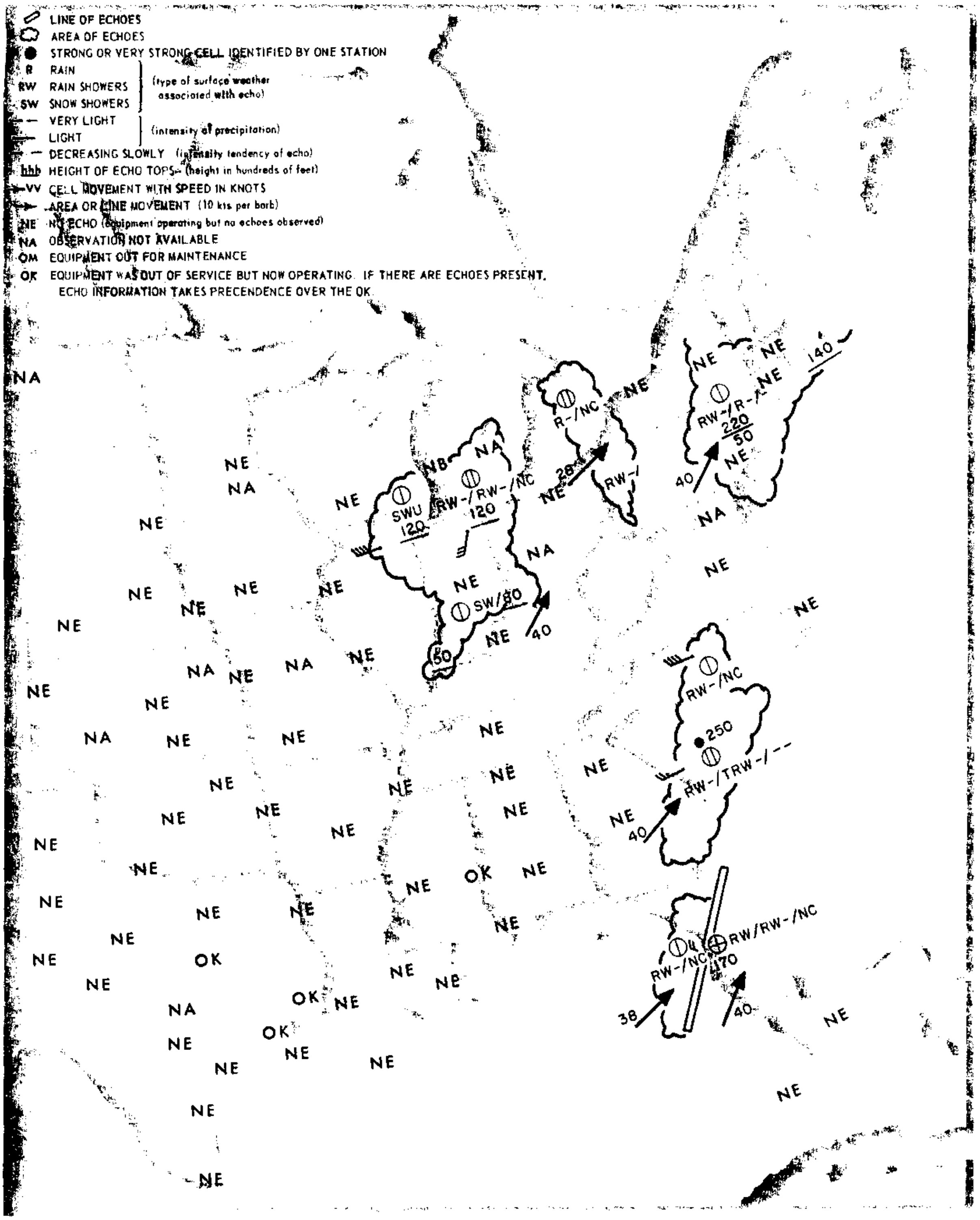


FIGURE 150. Radar summary chart, 1145 GMT, March 5, 1964.

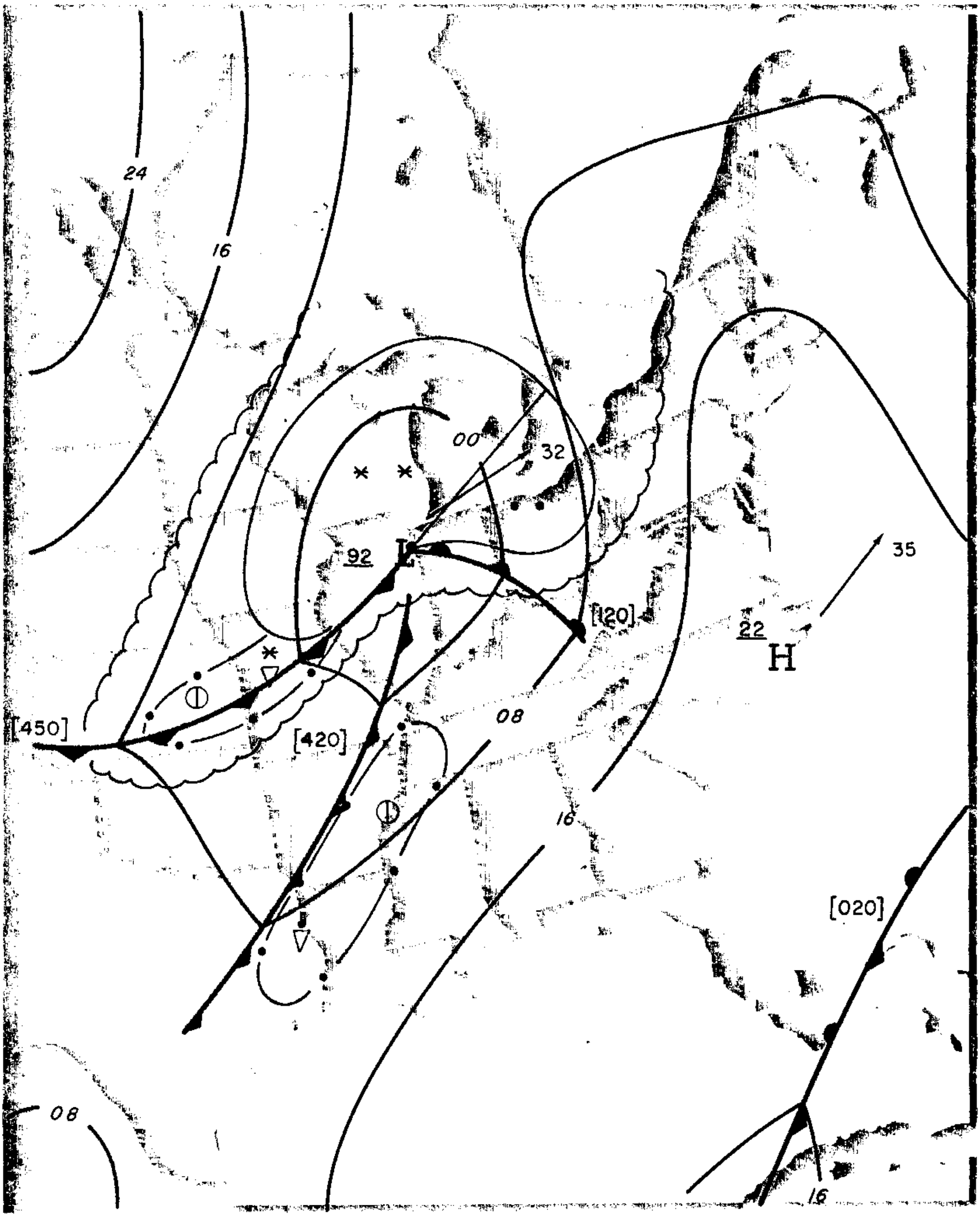


FIGURE 151. Prognostic surface weather chart for 0000 GMT, March 7, 1964.

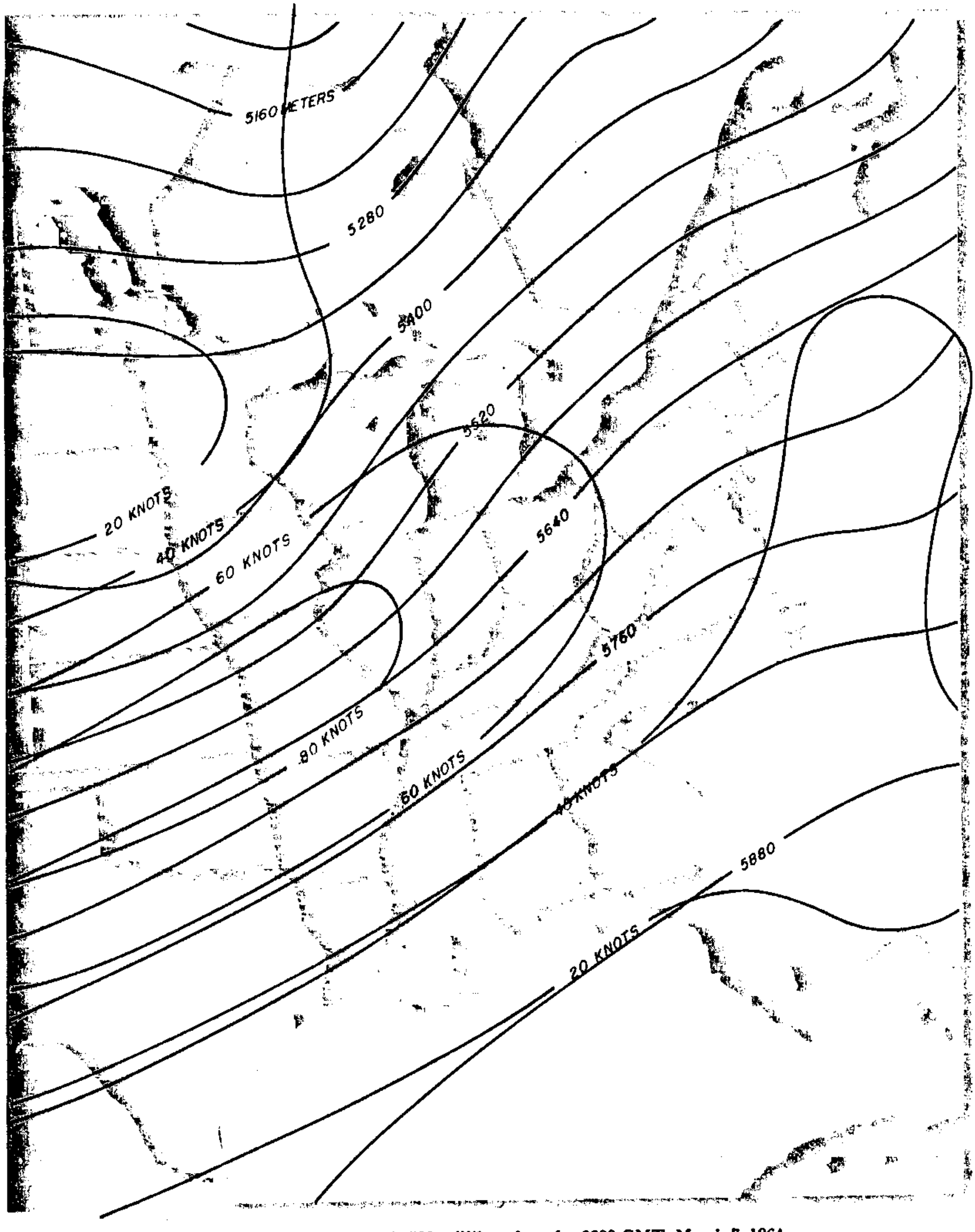


FIGURE 152. Prognostic 500 millibar chart for 0000 GMT, March 7, 1964.

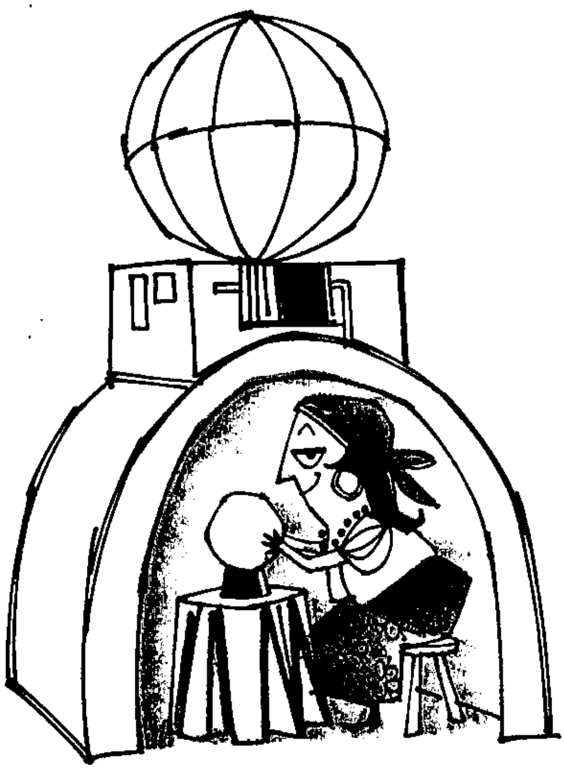
jet streams and isotachs are included on many of the higher level prognostic charts and most of the surface prognostic charts include current or accumulated precipitation and forecast cloud patterns.

PROGNOSTIC SIGNIFICANT WEATHER CHARTS

Prognostic Significant Weather Charts are transmitted every 6 hours over both the High Altitude Facsimile Circuit and the National Facsimile Circuit. Those on the High Altitude Facsimile Circuit serve both domestic and international flights, while those on the National Facsimile Circuit serve high altitude domestic flights. Prognostic Significant Weather Charts are transmitted on the National Facsimile Circuit primarily to serve private and business turbo-prop and pure jet aircraft pilots who do not have ready access to the material transmitted over the High Altitude Facsimile Circuit. These charts on the National Facsimile Circuit are for levels between 400 mb. (approximately 24,000 feet) and 150 mb. (approximately 45,000 feet). Domestic flights at lower levels depend primarily on the products of FAWS.

Prognostic Significant Weather Charts contain the following forecast features:

- Fronts are entered with arrows along them to indicate the expected direction of movement; speed of movement in knots is written near the arrows.
- Positions of centers of high and low pressure are indicated by block letters "H" and "L" respectively with the values of central pressure in millibars. Direction and speed of movement are indicated in the same manner as for fronts.
- Significant weather areas are outlined by scalloped or broken lines. The type of significant weather is entered using standard abbreviations or symbols (see app. III) with vertical extent in hundreds of feet. Areas of clear air turbulence (CAT) are outlined with *heavy* broken lines (one-half inch segments).
- Only clouds associated with significant weather and cirrus clouds are entered. Cloud areas (as with significant weather other than clear air turbulence) are outlined by *scalloped* lines. Types of clouds are entered, using standard abbreviations (see app. III), with bases and tops in hundreds of feet.
- The heights of the 0° C. isotherm are indicated by dashed lines at intervals of 5,000 feet. Each isotherm is labeled as 0° C., followed by the height in hundreds of feet.
- Sea level isobars (when included) are entered with thin solid lines.



Chapter 17

AVIATION WEATHER FORECASTS

Chapter 14 mentioned that the Flight Advisory Weather Service (FAWS) devotes its entire efforts toward meeting the requirements of aviation interests. The most important function of FAWS is the preparation of the aviation weather forecasts and advisories which are discussed in detail in this chapter. Aviation forecasts not made by FAWS are identified in the discussion.

12-HOUR TERMINAL FORECASTS (FT1)

Valid for 12 hours, these forecasts (see fig. 153) are prepared by FAWS for specific terminals. Prepared every 6 hours, they are transmitted on the Service A circuit (s) serving the issuing FAWS office to replace prior issuances. Forecasts for selected more distant terminals, which are carried on other Service A circuits, are relayed to the near-by circuit and vice versa.

CONTENT

Each terminal forecast includes heights and amounts of sky cover, ceiling identifier "C" when appropriate, visibility, weather, and/or obstruction to vision, surface wind, and, as necessary, remarks. Terminal forecasts do not include specific information concerning cloud tops or hazards such as icing and turbulence.

TIME USED

The filing time and valid time are shown in Greenwich mean time, while time changes in the body of the forecast are in local standard time. The weather conditions stated immediately following the terminal identifier are expected to occur at the beginning of the valid time.

SYMBOLS AND NOTATIONS

Symbols and notations used in terminal forecasts are the same as those used in Aviation Weather Reports, and appear in the same order.

CEILING IDENTIFIER

The forecast ceiling is identified by the letter

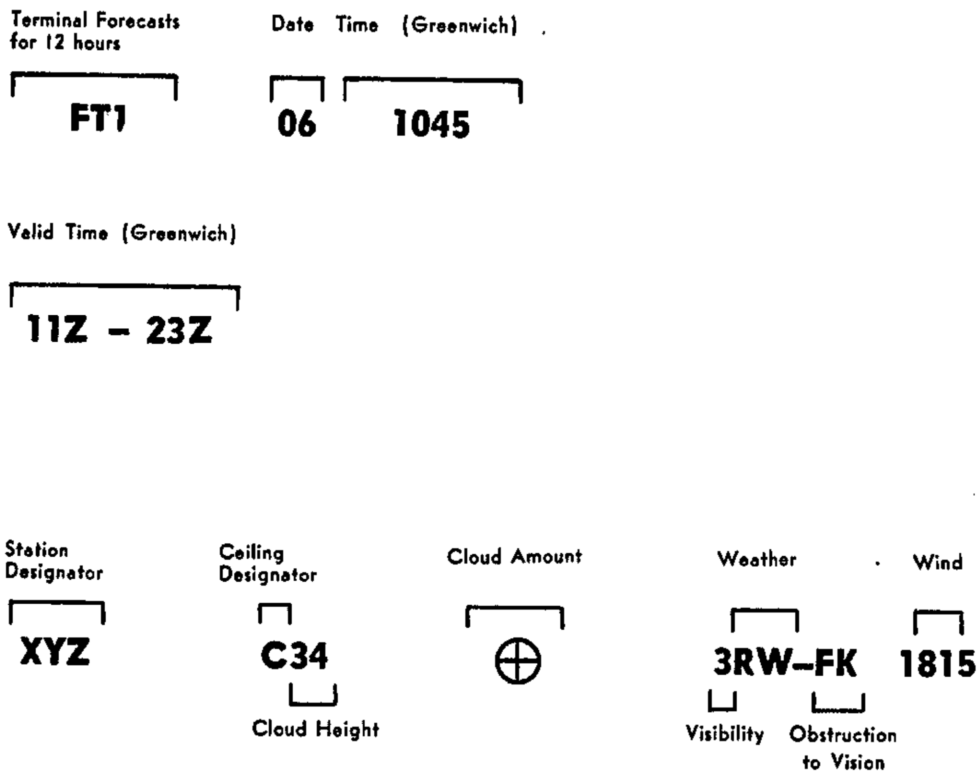


FIGURE 153. A 12-hour terminal forecast.

"C" immediately preceding the height figures for the layer representing the ceiling.

CLOUD HEIGHTS AND SKY COVER

The heights of cloud bases or vertical visibility into a total surface-based obscuration are indicated in ascending order *above the ground.* Cloud coverage and surface-based obscurations are indicated by the standard symbols ○, ⌽, ⦷, ⊕, −⌽, −⦷, −⊕, −X, and X. Sky cover includes all cloud layers up to and including the ceiling layer (if any) and any layers significant to flight operations above a broken layer; for example, 8⌽C17⦷50⊕. Adjacent broken or overcast layers with bases above 5,000 feet are considered as one layer when the tops of the lower layer are less than 3,000 feet from the base of the upper layer. Thus, if the FAWS forecaster expected conditions of C60⦷80⊕, he would code this condition C60⊕.

VISIBILITY

A forecast of prevailing visibility appears only if it is expected to be 8 statute miles or less. Weather and/or obstructions to vision follow the visibility value when the visibility is forecast to be 6 statute miles or less, as in the examples: 6K, 3R.

SURFACE WIND

Surface wind is shown by using two numbers to indicate the direction (to 36 points of the compass and with reference to true North) from which the wind is expected to blow, followed by the speed in knots. If the wind speed is forecast to be less than 10 knots, the entire wind group is omitted. If gusty wind conditions are expected, this is indicated by the letter "G" following the speed, i.e., 2425G which means "wind two four zero degrees, 25 knots and gusty." Peak gusts are shown following the "G" when gusts are expected to equal or exceed 35 knots; i.e., 2425G35 means "wind two four zero degrees, 25 knots, peak gusts 35 knots."

EXPECTED CHANGES IN WEATHER CONDITIONS

Significant changes in weather conditions are included if they are expected. A figure group in local standard time preceding the forecast changes shows the time that changes are expected to occur. The absence of indicated forecast changes implies generally uniform conditions throughout the 12-hour period of forecast validity. A gradual transition from one condition to another is indicated by modifying remarks.

READING THE FORECAST

Following are several examples of parts of terminal forecasts as they would appear on teletypewriter. The interpretation of each is given following the example. Notice that omission of an element can imply a forecasted condition just as though it were explicitly stated.

EXAMPLES	*INTERPRETATION*
30⌽C50⦷	Three thousand scattered, ceiling five thousand broken, (visibility greater than 8 miles, wind less than 10 knots.)
C3X1/2R−F	Ceiling three hundred, sky obscured, visibility one-half (mile), light rain and fog, (wind less than 10 knots.)
○	Clear, (visibility greater than 8 miles, wind less than 10 knots.)
50⌽100−⦷ C250⊕ 3615G.	Five thousand scattered, one zero thousand thin broken, ceiling two five thousand overcast, (visibility greater than 8 miles), wind three six zero degrees, one five knots and gusty (when gusts are expected to equal or exceed 35 knots, the gust speed will be entered following the letter "G," i.e. 3615G40).

GROUPING OF FORECASTS

Several terminal forecasts may appear under one heading with each forecast beginning on a separate line. When the same conditions are forecast for one terminal as for another, this may be indicated by using "DO", meaning ditto, as shown in the following example:

BUR C15⦷ 3215. 1730P ○
LAX DO BUR

AMENDED TERMINAL FORECASTS

Amended terminal forecasts are issued by the FAWS forecaster principally when it is advisable for safety and efficiency of aircraft operations, including flight planning, dispatching, operational control, and in-flight assistance to aircraft. The forecaster considers the VFR and IFR operating minimums at each terminal, along with the following criteria:

(1) A thunderstorm was forecast, but later is not expected to occur.
(2) A thunderstorm was not forecast, but later is expected to occur or does occur.
(3) The surface wind was forecast less than 15 knots, but later is expected to reach or is reported as 25 knots or more.
(4) The surface wind was forecast 25 knots or more, but later is expected to be in error by 20 knots or more.
(5) Freezing precipitation at the surface or sleet was forecast, but later is not expected.
(6) Freezing precipitation at the surface or sleet was not forecast, but later occurs or is expected to occur.
(7) The ceiling was forecast at 2,000 feet or above, but later it changes to or is expected to be 1,000 feet or less.
(8) The ceiling was forecast at 1,000 feet or above, but later it changes to or is expected to be 500 feet or less.
(9) The ceiling was forecast below 1,000 feet, but later it changes to or is expected to be 2,000 feet or more.
(10) The ceiling was forecast below 500 feet, but later it changes to or is expected to be 1,000 feet or more.
(11) The visibility was forecast 5 miles or more, but later changes to or is expected to be 3 miles or less.
(12) The visibility was forecast 2 miles or more, but later changes to or is expected to be 1 mile or less.
(13) The visibility was forecast less than 3 miles, but later changes to or is expected to be 5 miles or more.
(14) The visibility was forecast less than 1 mile, but later changes to or is expected to be 2 miles or more.

Following is a sample amended terminal forecast taken from the teletypewriter circuit:

AMENDED FT1 SEA 061540
1540Z–22Z THU

BFI C4⊕11/2LF. 1200P C10⊕2L – F 2212

Sample FT1 Forecasts are given below as they appear on Service A:

FT1 121045
11Z–23Z WED

066
AMA 250–⦶ 2010. 1030C 250–⦷ 2018. 1630C COLD FROPA C50⊕3RW– 3320G35
LBB 250–⦶ 2010. 1000C C250⦷ 2018
GAG DO AMA

067
PNC ○ 1612. 1230C 40⦶ 1815 ⦶V⦷. 1500C C35⦷ 2020G CHANCE BRF
C10X1TRW+ 2225G45
BGS ○. 1000C 250–⦷ 2017

069
GSW C45⦷ 1810C ⦷V⊕. 1330C 40⦶250⦶ 2018
DAL DO GSW
OKC 40⦶ 1815.
TUL 40⦶100⦶ 2015

24-HOUR TERMINAL FORECASTS (FT2)

Valid for 24 hours, these forecasts have the same format as the 12-hour terminal forecasts, except that the FAWS center originating the forecast appears in the heading. They are issued each 6 hours for major terminals only and are transmitted on *Service C* teletypewriter circuits. If the forecast for OKC, in the previous example, also appeared in a 24-hour terminal forecast, the time period would be extended, and it might appear as follows:

FT2 GSW 121115
11Z WED–11Z THU

OKC 40⦶ 1815. 1700C 40⦶C100⦷ 2020G. 1900C C40⦷100⦷ 2020G35. 0200C C20⊕3RW 2025G40

A sample FT2 forecast as it might appear on Service C teletypewriter is given below:

FT2 MKC 131115
11Z TUE–11Z WED

DSM C2X3/4L–F 1410. 1230C C4X11/2F 1115 OCNL L–. 1800C C6⊕3R–F 1115. 0200C C10⊕6R–F 0520
LBF -X3GF. 0800C C100⊕ 3215 OCNL R–. 1200C C50⊕ 3220G40 OCNL R–. 1800C 30⦶C80⦷ 3215G. 0000C C120⦷ 3210
MKC 5⦶300–⦷2GFK. 1000C 300–⦷5HK 1412. 1300C 300–⦷ 2020G35. 2200C FROPA C50⊕ 3220G40 OCNL RW–. 0500C C25⦷ 3215G
OMA C1X1/4L–F 1110. 1100C C3X1F 0910 OCNL L–. 1400C C7⊕3F 0910. 1630C FROPA 10⦶C80⊕ 3220G40 OCNL RW–. 2100C C15⊕6RW– 3220G35. 0400C C25⊕ 3215G
ICT 300–⦷ 1815. 1000C 100⦶300–⦷ 2022G. 1800C FROPA C30⦷ 2920G OCNL C50⦷RW–. 0000C 30⦶150⦶ 3215

AREA FORECASTS (FA)

While terminal forecasts describe weather conditions at specific airports, area forecasts consider the weather on a regional basis and are intended primarily as enroute forecasts. They are also valuable in providing an indication of expected conditions at airports for which no FT is prepared. FA's include forecasts of cloud tops, icing, turbulence, and other hazards for use in preflight briefing. They are prepared every 6 hours for all areas of the United States, including Alaska and Hawaii, and are transmitted over Service A. Specific information is given for a 12-hour period, with an outlook for an additional 12 hours. These forecasts consist of the following sections, each written as a separate paragraph and in the following order:

- Heading
- Forecast Area
- Clouds and Weather
- Icing (and freezing level (s))
- Turbulence (when applicable)
- Outlook

HEADING

The heading identifies the forecast center, the type of forecast to follow, the scheduled filing time, and the valid period.

FORECAST AREA

This section identifies the geographic area covered by the forecast.

CLOUDS AND WEATHER

This section consists of a description of the amount and height of sky cover, cloud tops, location and movement of weather-producing fronts as necessary, surface visibility, state of weather and obstructions to vision, surface wind, and other information needed to describe flying conditions expected during the first 12-hour period. Abbreviated plain language normally is used, but authorized weather symbols sometimes are employed to describe the amount and height of sky cover, visibility and obstructions to vision.

Sky Cover. Sky cover is stated solely on the basis of the expected amount of coverage by individual layer, instead of by the summation principle used in *Aviation Weather Reports* and terminal forecasts. Adjacent broken or overcast layers with bases 5,000 feet or higher above ground and with less than 3,000 feet vertical separation are considered as one layer.

Cloud Heights. Ordinarily heights are stated in hundreds of feet, using intervals of 100 feet for heights up to 3,000 feet above ground in plains and valley areas. Above 3,000 feet, intervals of 500 to 1,000 feet are used. Heights may be with reference to mean sea level or above ground, whichever most effectively conveys the information. However, heights are, in each instance, specifically identified as to the height reference. Ceiling heights are always with reference to above ground as the "C" implies, and no other identification is necessary. For example:

C30⊕ and 100⦶ MSL

Cloud Tops. The height of cloud tops is stated for cloud layers with bases 20,000 feet MSL or lower. Cloud top information is written in hundreds of feet, using mean sea level as a reference plane, and is identified by the use of the word "TOPS." As an example:

2⦶C5⊕ TOPS 30

Visibility. Surface visibility of more than 8 statute miles is omitted from the forecast. When visibilities are forecasted to be 6 statute miles or less, the state of weather and obstructions to vision will be included. This rule is the same as for terminal forecasts. Flight or slant visibility is not included in the routine forecasts, but is sometimes implied by the forecasted clouds, weather, and surface prevailing visibility.

Weather and Obstructions to Vision. Occurrences of weather and obstructions to vision are written in contracted form (i.e., SNW, DRZL) when included with a plain language statement. They are indicated in symbol form (S, L, etc.), using the plus or minus signs in accordance with aviation reporting procedures, when written as part of a complete symbolic group such as C8⊕3S–

Surface Winds. Surface winds are stated in symbolic form for any area where winds are expected to reach sustained speeds of 25 knots or more. Directions are stated with reference to true north and speeds are given in knots. The contraction "SFC WND" will precede the direction and speed group. Gusty surface winds included in the plain language or abbreviated text portion of the forecast are denoted by the term "GUSTY" or "GUSTS TO.........................." or, when part of the complete symbolic group, by the form "25G", "25G40", or "G65".

ICING

This section, identified by the contraction "ICG," includes a statement of expected icing conditions plus the height of the freezing level. Types of icing (clear, rime, or mixed) are indicated by the contractions CLR, RIME, or MXD. Icing intensities are described as light, moderate, or heavy, by the contractions LGT, MDT, and HVY. Sometimes contractions such as ICGIC, ICGIP, and ICGICIP, meaning respectively "icing in clouds," "icing in precipitation" and "icing in clouds and in precipitation," are used in combination with icing type and intensity.

For example:

MDT CLR ICGICIP

Qualifying terms such as "probably," "likely," and "locally" are used when these add to the value of the forecast, such as:

MXD ICGIC LKLY

A forecast of no icing is written "NONE." Even when no icing is forecast, the expected freezing level is indicated. Heights of icing and the freezing level are stated in hundreds of feet above mean sea level.

TURBULENCE

This section, identified by the contraction, "TURBC," is included when turbulence of any intensity sufficient to affect safety of aircraft is expected. The terms MDT, SVR, and EXTRM are used to describe intensity. If no important turbulence is expected, this section is omitted. Heights are given in hundreds of feet above mean sea level.

OUTLOOK

This section contains a brief statement of conditions expected in the 12-hour period immediately following the forecast period. Emphasis is on weather conditions significant to flight planning.

AMENDED AREA FORECAST

The FAWS centers in the contiguous 48 States and in Hawaii do not amend scheduled Area Forecasts since In-Flight Advisories (FL's) serve this purpose, but the FAWS center in Alaska amends Area Forecasts as needed to meet operating requirements.

SAMPLE AREA FORECAST

Below is a sample Area Forecast as it would appear on Service A teletypewriter. Following the example is an interpretation of the forecast:

FA ATL 071245
08E–20E WED

WRN NC WRN SC NRN GA ALA EXCP MOBILE AREA

CLDS AND WX. ○ OVR SRN AND CNTRL ALA

OVR NRN ALA AND NRN GA C15–20⦷V⊕ TOPS 40–60 BCMG MSTLY C30⦷V⦶ TOPS 40 BY 12E AND 35⦶ BY 14E AND ○ BY 19E

OVR WRN SC 40⦶V⦷ MSL TOPS 90 BCMG ○ BY 19E

OVR WRN NC C20–40⦶V⦷ TOPS 100–120 LCLY C10⊕7 IN THE MTNS WITH OCNL C10X2S– BCMG C40⦷V⦶ TOPS 80 BY 12E WITH A FEW SNW FLRYS PRSTG IN THE MTNS. CLRG BY 20E.

ICG. LGT TO MDT RIME ICGIC WITH CHANCE OF MDT MXD ICGIP WRN NC TIL 12E. FRZG LVL SFC OVR THE WRN CAROLINAS AND NRN GA SLPG TO 30–40 CNTRL AND SRN ALA LFTG TO 25 WRN NC AND 50 SRN ALA BY AFTN

TURBC. MDT BLO 80–120 OVR WRN NC WRN SC NRN GA WITH OCNL SVR TURBC OVR AND ALG E SLPS OF MTNS. TURBC WL DMSH LATE AFTN. MOST PRBL AREA OF MDT CAT 250–350 OVR THE WRN CAROLINAS AND NRN GA ESPECIALLY OVR THE MTNS

OTLK. 20E WED–08E THU. ○ OVR AREA BCMG C200⦶ OVR WRN ALA BY DABRK. VSBY UNRSTD LWRG LCLY TO 4KH BY 06E

The above area forecast was issued by the Atlanta FAWS center the 7th day of the month at one two four five Greenwich mean time and is valid from zero eight zero zero Eastern Wednesday until two zero zero zero Eastern Wednesday.

The forecast area includes western North Carolina, western South Carolina, northern Georgia, and Albama except for the Mobile area.

CLOUDS AND WEATHER. Clear over southern and central Albama. Over northern Alabama and northern Georgia, ceiling one thousand five hundred to two thousand broken variable to overcast, tops four thousand to six thousand, becoming mostly ceiling three thousand broken variable to scattered with tops four thousand by one two zero zero Eastern, and three thousand five hundred scattered by one four zero zero Eastern, and clear by one niner zero zero Eastern.

Over western South Carolina, four thousand scattered variable to broken, tops niner thousand, becoming clear by one niner zero zero Eastern.

Over western North Carolina, ceiling two thousand to four thousand scattered variable to broken, tops one zero thousand to one two thousand, locally ceiling one thousand overcast and visibility seven miles in the mountains, with occasional ceiling one thousand, sky obscured, and visibility two miles in light snow, becoming ceiling four thousand broken variable to scattered, tops eight thousand by one two zero zero Eastern, with a few snow flurries persisting in the mountains. Clearing by two zero zero zero Eastern.

ICING. Light to moderate rime icing in clouds with a chance of moderate mixed (rime and clear) icing in precipitation over western North Carolina until one two zero zero Eastern. The freezing level will be at the surface over the western Carolinas and northern Georgia, sloping to three thousand to four thousand over central and southern Alabama, and lifting to two thousand five hundred over western North Carolina and five thousand over southern Alabama by this afternoon.

TURBULENCE. Moderate turbulence below eight thousand to one two thousand over western North Carolina, western South Carolina, and northern Georgia, with occasional severe turbulence over and along the east slopes of the mountains. Turbulence will diminish late in the afternoon. The most probable area of moderate clear air turbulence is between two five thousand and three five thousand feet over the western Carolinas and northern Georgia, especially over the mountains.

OUTLOOK. From two zero zero zero Eastern Wednesday until zero eight zero zero Thursday —clear over the area, becoming ceiling two zero thousand broken over western Alabama by daybreak. Visibility unrestricted, lowering locally to four miles in smoke and haze by zero six zero zero Eastern.

WINDS ALOFT FORECASTS (FD)

Winds Aloft Forecasts are made every 6 hours for 89 selected locations in the contiguous States and are transmitted on Service A. Twice a day these forecasts are computer-produced by the National Meteorological Center (0550 and 1750Z), and twice a day they are manually produced by the FAWS centers (1150 and 2350Z). All four Winds Aloft Forecasts issued daily are for a twelve-hour period, but those which are computer-produced are in the form of two six-hour forecasts, each representative of its entire six-hour period.

Each Winds Aloft Forecast includes the expected wind direction and speed for 3,000 feet (for stations having a terrain elevation of 2,000 feet or lower), 5,000 feet (for stations having a terrain elevation of 4,000 feet or lower), 10,000 feet, 15,000 feet, 20,000 feet, and 25,000 feet. All heights are in thousands of feet above mean sea level. Temperature forecasts are appended to all wind forecasts above 3,000 feet, except no temperature forecasts are appended to the 5,000-foot wind forecast when this is the lowest level forecast.

Direction of the wind is in reference to true north and is stated in two digits. For example, 270 degrees is written as 27. (See below for the exception to this rule.)

Speed of the wind is in knots. Speeds less than 10 knots are shown as 08, 06, etc. In the manually produced Winds Aloft Forecasts, if the speed is expected to be less than 5 knots, the group "9900" is inserted instead of the direction and speed. This group is spoken of as "LIGHT AND VARIABLE." Forecast winds of 100 to 199 knots are indicated by subtracting 100 from the speed and adding 50 to the direction. For example, a forecast of 250 degrees, 145 knots would read 7545.

MANUALLY PRODUCED WINDS ALOFT FORECASTS

When significant changes in wind direction, wind speed, or temperature (as outlined below) are expected at any time during the 12-hour forecast period, the manually produced Winds Aloft Forecasts issued by FAWS centers show the new values on a separate line as indicated in the two sample forecasts below:

FD MEM 242350
00—12Z FRI

LVL	3000	5000 FT	10000FT	15000FT	20000FT	25000FT
HRO	2430	1945+11	2140+01	2445—11	2650—16	2665—25
04Z	3035	2850+05	2740—01	2645—12	2650—16	2670—26
06Z	3240	3140—01	3045—07	2450—15		
DYR	2615	2430+09	2325+01	2540—12	2645—15	2660—25
10Z	3035	2850+05	2740—01	2645—12	2645—15	2665+25

Note in the above example that the changes in wind direction, wind speed, or temperatures are indicated for the standard levels up to and including the level above which no change is expected. Times of changes are indicated to the nearest whole hour in Greenwich Mean Time (Z).

The following guidelines are used by FAWS forecasters in deciding whether or not a change forecast is necessary:

(1) The wind speed is 25 knots or less, and the direction is expected to change by 45° or more.

(2) The wind speed is more than 25 knots, and the direction is expected to change by 30° or more.

(3) The wind speed is 25 knots or less and is expected to change as much as 10 knots or more.

(4) The wind speed is more than 25 knots and is expected to change as much as 15 knots or more.

(5) An expected change in temperature of 5° C. or more, except 3° C. or more at the 5,000-foot level.

COMPUTER-PRODUCED WINDS ALOFT FORECASTS

The Winds Aloft Forecasts produced by the National Meteorological Center cover the twelve-hour period with two consecutive six-hour forecasts. Part of a typical transmission is given below:

FD1 WBC 010550
06—12Z WED

LVL	3000	5000 FT	10000FT	15000FT	20000FT	25000FT
MLT	2415	2722+02	2930—05	3133—13	3238—18	3343—24
BOS	2015	2328+06	2633—01	2936—10	3043—15	3048—21

12—18Z WED

LVL	3000	5000 FT	10000FT	15000FT	20000FT	25000FT
MLT	2925	2833+00	3030—06	2828—13	3035—17	3140—22

IN-FLIGHT WEATHER ADVISORIES (FL)

In-Flight Weather Advisories are issued by FAWS centers for the purpose of giving airmen *in flight* advance notice of impending weather developments or trends that are potentially hazardous. They serve both civil and military aviation.

SIGNIFICANT METEOROLOGICAL (SIGMET) ADVISORIES

SIGMET advisories concern weather of particular significance to the safety of transport category (large multi-engine) aircraft *as well as smaller aircraft*. They are issued whenever any of the following phenomena are either known to exist or are expected to begin within 2 hours:

- Tornadoes
- Lines of thunderstorms (squall lines)
- Large hail (¾ inch or more in diameter)
- Severe or extreme turbulence
- Heavy icing
- Widespread duststorms or sandstorms that reduce visibility to 2 miles or less

ADVISORIES FOR LIGHT AIRCRAFT

These advisories concern weather that is potentially hazardous to small single and twin-engine aircraft, but is not necessarily hazardous to those of the large transport category. ADVISORIES FOR LIGHT AIRCRAFT are issued whenever the following either are known to exist or are expected to begin within 2 hours:

- Moderate icing
- Moderate turbulence
- Winds of 40 knots or more within 2,000 feet of the ground
- The initial onset of visibility less than 2 miles or ceilings below 1,000 feet, including ceiling and visibility conditions near mountain ridges and in mountain passes

DISTRIBUTION OF IN-FLIGHT WEATHER ADVISORIES

In-Flight Weather Advisories of both types are broadcast by FAA Flight Service Stations on the voice channels of various FAA navigational aids. Upon receipt of a SIGMET advisory issued by the FAWS center associated with the Air Route Traffic Control Center (ARTCC), the ARTCC controllers make an alerting broadcast on all frequencies serving sectors which have active traffic. This alerts IFR aircraft to monitor VHF omnirange (VOR) voice channels for the SIGMET advisory.

Although issued primarily to serve airmen in flight, In-Flight Weather Advisories also amend area forecasts and are, therefore, distributed on Service A as unscheduled *priority* traffic.

DESIGNATION OF IN-FLIGHT WEATHER ADVISORIES

If a SIGMET advisory is issued for the same area and time period as that of an Advisory for Light Aircraft, the Advisory for Light Aircraft will follow the SIGMET advisory in the same teletypewriter message as an ADDITIONAL ADVISORY FOR LIGHT AIRCRAFT.

Each FAWS center identifies each FL issued. The first advisory issued after midnight local standard time, whether SIGMET, ADVISORY FOR LIGHT AIRCRAFT, or in combination, is designated "Alpha 1". Each succeeding (related) advisory, whether SIGMET, ADVISORY FOR LIGHT AIRCRAFT, or in combination, retains the same phonetic alphabetical designation, but with the next number, i.e., Alpha 2, Alpha 3, etc. If a SIGMET or ADVISORY FOR LIGHT AIRCRAFT becomes a combination advisory or vice versa, the succeeding advisory retains the alphabetical designation, but with the next number. For example, ADVISORY FOR LIGHT AIRCRAFT ALPHA 2 could become, on the next issuance, SIGMET ALPHA 3 with the ADVISORY FOR LIGHT AIRCRAFT appended. Then SIGMET ALPHA 3 could become downgraded, and the next issuance would read:

CANCEL SIGMET ALPHA 3
ADVISORY FOR LIGHT AIRCRAFT
ALPHA 4

In cases where a potentially hazardous weather situation develops in a second and distinctly separate sector within a FAWS area, the second series of advisories is designated BRAVO 1, BRAVO 2, etc.

CANCELLATION OF IN-FLIGHT WEATHER ADVISORIES

In-Flight Weather Advisories are canceled by (1) expiration (for example, an FL valid until 1500 PST expires automatically at 1500 PST if no new FL for that sector has been issued), (2) a statement in a succeeding FL canceling a SIGMET, ADVISORY FOR LIGHT AIRCRAFT, or both, and (3) the issuance of a succeeding identified advisory (for example, SIGMET BRAVO 2 automatically cancels SIGMET BRAVO 1).

The time interval between issuance of the advisory and its expiration never exceeds 4 hours, and an earlier expiration time is given when appropriate.

SAMPLE IN-FLIGHT WEATHER ADVISORY

Following is an example of an In-Flight Weather Advisory as it would appear on the Service A teletypewriter:

FL DCA 090900
0400E–0800E SUN

SIGMET ALPHA 2. SVR CAT EXTENDING FM S CNTRL VA THRU DEL AT 140 TO 240 MSL. ADDNL ADVY FOR LGT ACFT. OVR ERN VA ERN MD AND DEL MDT ICGIC 20 TO 80 MSL. NWLY WNDS IN LWR LVLS WL INCR TO 40 TO 50 KT SOON AFT 0700E ACPYD BY MDT TURBC.

HURRICANE ADVISORIES (WH)

When a hurricane is threatening an area, these advisories are transmitted four times daily on *Service C*. In plain language, they include the location, extent, intensity, and movement of the hurricane, as well as a forecast of these general features. Service A circuits serving areas affected by the hurricane also carry the complete advisory, but the abbreviated advisory is used for national distribution on Service A.

Hurricane Advisories are used by aviation interests in planning such large-scale activities as the evacuation of aircraft from threatened locations. Specific information on aviation weather hazards associated with the hurricane is contained in appropriate Area and Terminal Forecasts and in In-Flight Weather Advisories. However, these forecasts make reference to the latest Hurricane Advisory for more complete information on the hurricane.

An example of an abbreviated Hurricane Advisory follows:

WH MIA 181010
HURCN IONA AT 05E CENTRD 29.4N 75.2W OR 300 MI E OF JACKSONVILLE FLA EXPCD TO MOV NW ABT 12 KT. MAX WNDS 110 KT OVR SML AREA NEAR CNTR AND HURCN WNDS WITHIN 55–75 MI.

SEVERE WEATHER OUTLOOKS (AC)

During the appropriate season, an outlook for thunderstorm activity in the contiguous States is transmitted on Service A early each morning by the Severe Local Storm (SELS) Forecast Center. This outlook, stated in rather general terms and in plain language, describes the prospects of severe weather during the next 24 hours. The term "SVR LIMITS," meaning conditions requiring the issuance of detailed severe weather forecasts, is used frequently in the text. Aviation interests use this information on the probability of severe local storms in operational planning.

A sample Severe Weather Outlook (AC) is shown below:

100
AC MKC 051040
MKC AC 050440C
WIDESPREAD TSHWR ACTVY EXPCD TDA ALG FRONTAL BNDRY FM WRN APLCNS THRU OHIO VLY ALG NRN ILL AND WWD INTO CNTRL IA NRN NEB WRN DKTS AND ERN MONT ALG ERN RCKYS. THE USUAL AMS TSHWRS WL AGN OCR ALG THE CSTL CAROLINAS AND GLF CST. CNVGG PATN OF JTSTR FM GRTLKS EWD INDCS TSHWR PCPN IN ILL IND AND OHIO WL BE PRINLY OVRNG AND RATHER COPIOUS BUT BLO LIMITS. MOST LKLY AREA TO ATTAIN SVR LMTS WL BE ALG INSTBY LINE FRMG EARLY AFTN ALG E SLP RCKYS FM CNTRL MONT SWD INTO CNTRL WYO WITH LINE MOVG INTO CNTRL DKTS AND CNTRL NEB. MAGOR.

SEVERE WEATHER FORECASTS (WW)

Severe Weather Forecasts, numbered serially during the year, are issued as required. These plain-language forecasts are of particular interest to air traffic service personnel, local weather offices, and pilots. The content of SELS forecasts is reflected in Terminal and Area Forecasts and in In-Flight Weather Advisories.

The general format of Severe Weather Forecasts is shown in the following example:

100
WW MKC 050140

MKC FCST NR 423 050140

AREA ONE . . . . SVR TSTM FCST

A . . . . ALG AND 60 MI EITHER SIDE OF A LINE FM 30 MI SW OF MASON CITY IA TO 20 MI S OF PEORIA ILL. VALID CURRENT TIL 0600Z. PUB FCST ISSUED.

B . . . . SCTD SVR TSTMS WITH HAIL TO ¾ INCH DIAM EXTRM TURBC AND MAX SFC WND GSTS TO 60 KT. SCTD CBS MAX TOPS TO 55 THSD FT.

C . . . . SQLN DVLPG IN NWRN IA EXPCD TO MOV SE ABT 35 KT.

REMARKS. THIS FCST REVISED WW 421 AREA TWO

SMITH.

An explanation for each part of the format follows:

AREA (number)—TYPE OF FORECAST (Tornado, etc.) Forecasts for more than one area may be issued under the same heading, in which case the areas are numbered serially within the issuance. The type of forecast follows the numbered area, as TORNADO FCST or SVR TSTM FCST.

A—This paragraph describes the area in which the severe weather conditions are forecast and states the valid time. If a forecast applicable to the general public has been issued, or will be issued, the statement PUB FCST ISSUED or PUB FCST WIBIS is included. If one of these statements is not included, the forecast is of primary concern to aviation only, and the user should guard against any dissemination and unnecessary alarm to the general public.

B—This paragraph states the number of storms expected as a few, scattered, numerous, etc. It also describes the severe conditions expected with respect to hail, turbulence, and surface winds.

C—This paragraph describes the weather system that is expected to cause the severe conditions, and may give details of reported weather of significance.

REMARKS — as appropriate to complete understanding and usage of the forecast.

SIMPLIFIED SURFACE ANALYSES AND PROGNOSES (AS–2 and FS–1)

At 6-hour intervals beginning at 0150 GMT each day, a simplified surface analysis, identified by the heading AS–2, is transmitted via Service A teletypewriter. At two of these times, 0150 and 1350 GMT, the analysis is followed in the same transmission by a surface prognosis which is effective 24 hours after the time of the analysis to which it is appended. In addition, at approximately 6-hour intervals (0240, 0940, 1440, and 2040 GMT), a 12-hour surface prognosis, identified by the heading FS–1, is transmitted. The analysis designates the positions and strengths of various pressure and frontal systems. The prognosis indicates the forecast future positions of these systems.

The AS–2 and the FS–1 are in coded forms, and, in order to be useful, the coded message must be translated by plotting the information onto a blank chart of the United States. Specifically referred to in the AS–2 and the FS–1 are the locations and forecast movements of the following systems, if applicable:

Highs
Lows
Tropical Storms

Occluded Fronts
Cold Fronts
Warm Fronts
Stationary Fronts
Squall Lines
Troughs
Ridges
Other surface phenomena as necessary

Highs, lows, and tropical storm centers are located by one point to the nearest whole degree of latitude and longitude. Surface locations of other phenomena, such as fronts, also are given to the nearest whole degree of latitude and longitude, but more than one point is necessary to indicate the position of frontal systems. Intensity values, such as weak, moderate, strong, and intense, are included with all weather systems, except for highs, lows, tropical storms, troughs, and ridges. Central pressures are specified for the highs, lows, and tropical storms.

REGIONAL WEATHER PROGNOSES (FN—1)

Regional Weather Prognoses are issued every 6 hours via Service A teletypewriter for the Far West (U.S.) by the FAWS center in San Francisco (see fig. 119). These forecasts are valid for 24 hours, and their primary purpose is to meet the needs of pilots who obtain preflight briefings at weather offices having only information distributed by teletypewriter.

Regional Weather Prognoses consist of the following sections:

Heading
Forecast Region
Prognosis

HEADING

This section consists of the term "FN–1," followed by the forecast center originating the forecast and a 6-digit date-time group in Greenwich mean time (GMT).

FORECAST REGION

Directly beneath the heading (without a skipped line) is the designator for the forecast region and the 24-hour valid period of the forecast in local standard time.

PROGNOSIS

This section, identified by the term "PROG," contains a brief statement about the location, expected movement, and the development of dominant synoptic features (air masses, fronts, and pressure systems) that are expected to affect materially the forecast region during the next 24-hour period. Detailed statements of positions of fronts and pressure systems normally are confined to the region of forecast responsibility.

An example of a Regional Weather Prognosis in Service A teletypewriter form is given below, followed by an interpretation of this forecast:

FN–1 SFO 291155
SAN FRANCISCO REGION 04P WED–04P THU

PROG. MDTLY LOW PRES OVR WPLTO AREA WITH HIR PRES OFF PAC CST AND E OF RCKYS. NO DEFINITE FRONTS. HI PRES RDG ALF BC TO ERN NEW MEX MOVG VERY SLOLY EWD AS WK LOW ALF CNTRL CALIF-NEV BRDR AREA MOVS EWD TO UTAH AND BCMS A FLAT TROF ALF BY LATE TDA

This Regional Weather Prognosis was issued by the San Francisco forecast center the twenty ninth day of the month at one one five five Greenwich Mean Time. It is valid from zero four zero zero Pacific Standard Time Wednesday until zero four zero zero Pacific Standard Time Thursday for the San Francisco region.

PROG. Moderately low pressure over the western Plateau area with higher pressure off of the Pacific Coast and east of the Rockies. There are no definite fronts. High pressure ridge aloft extending from British Columbia (Canada) to eastern New Mexico moving very slowly eastward as weak low aloft in the central California and Nevada border area moves eastward to Utah and becomes a flat trough aloft by late today.

Chapter 18

USING AND HELPING THE WEATHER SERVICE

Effective aviation weather briefing requires a "mutual understanding" between the pilot and the weather briefer. *Team effort is an important part of a successfully completed flight plan.* For example, the pilot greatly assists the briefer by telling him such things as his estimated time of departure, his proposed route, his estimated time en route, alternate destinations that he can reach within the limitations of his aircraft, and his own capabilities as a pilot. If the pilot plans a long nonstop trip, his weather briefing will be more accurate and more complete if he gives the briefer reasonable advance notice.

This chapter deals with the importance of obtaining preflight weather briefings, how the pilot can best use the weather information available to him, the pilot's role as part of the weather service, and some of the ways he can contribute effectively to the team effort.

ACCESSIBILITY OF WEATHER BRIEFING SERVICES

In past years, pilot weather briefing generally was conducted face-to-face between pilots and weathermen. This personalized service continues as an important part of the presenting function (ch. 14), but in recent years the phenomenal increase in the number of General Aviation pilots (pilots other than airline and military) has required other methods of distributing aviation weather information.

Located for the most part at busy airports, Weather Bureau and FAA weather briefing offices number about 600 (see fig. 127). Since there are more than 8,000 airports in the nation, it is obvious that many pilots cannot easily obtain a face-to-face weather briefing. In a number of cities, a Weather Bureau Airport Station is located at air carrier airports. A Flight Service Station of the FAA is generally located on a high-activity General Aviation airport. Both a Weather Bureau office and a Flight Service Station are on the same airport in some cases.

Some fixed-base operators or other organizations on airports not served directly by either the Weather Bureau or the FAA have leased receive-only connections to the Service A teletypewriter circuit, and thereby can receive hundreds of weather observations each hour, as well as almost all of the forecast products of FAWS. Pilots who use this material *only* must be capable of translating the observations and forecasts in order to brief themselves on the weather situation.

Pilots departing from many of those airports having neither a Weather Bureau Airport Station nor an FAA Flight Service Station may call the latter on a foreign exchange telephone service provided by the FAA at no cost to the pilot. Weather Bureau briefings may be obtained in some cities through an unlisted telephone service available only to pilots (numbers are listed in the Airman's Information Manual). Many commercial radio broadcasts include information of particular interest to aviators. The pilot also may receive aviation weather information from recorded weather briefings over telephone and radio (see ch. 14).

At some of the larger airports, neither the FAA nor the Weather Bureau briefing office may be readily accessible—even though they are on the airport. FAA is experimenting with closed-circuit television for use in briefing pilots at scattered locations on large airports. The military has used this medium successfully for a number of years. At the present time, most pilots on high-activity civil airports contact the briefing office by telephone or use one of the other local distribution methods (ch. 14). Some use only the recorded weather briefings.

WEATHER AND AIRCRAFT ACCIDENTS

In spite of the various weather briefing methods available, a large percentage of pilots in the General Aviation category probably receive either an incomplete weather briefing or no weather briefing at all prior to takeoff. Lack of weather knowledge and failure to obtain a weather briefing undoubtedly account for a considerable number of General Aviation accidents. In a recent year, for example, there were 4,400 accidents among pilots in this category, 420 of which were fatal. Thirty-three percent of the latter were attributed to loss of control of aircraft by non-instrument-rated pilots in adverse weather conditions. In about one-third of the cases, indications were that the pilot had not obtained sufficient information concerning en-route and destination weather. *Lack of availability of adequate weather service accounts for only a small percentage of aircraft accidents.*

Low ceilings and poor visibilities contribute in large degree to many weather-connected accidents. Strong and changeable surface winds also cause a large number of accidents. Other causes of weather-connected aircraft accidents are in-flight turbulence, snow, hail, structural icing, powerplant icing, thunderstorms, strong winds aloft, updrafts and downdrafts, smoke, and haze.

WHY SOME PILOTS FLY WITHOUT A WEATHER BRIEFING

The inaccessibility of the weather service at some airports is one of the primary reasons that some pilots do not receive a weather briefing prior to takeoff. When a briefing office is not available, some pilots do not bother to make a long-distance call. Others do not have a radio receiver capable of receiving the continuous transcribed weather broadcast or are outside of its reception range. Even in cases when the pilot could call a weather briefing office free, he often does not do so because he hasn't yet gained a lasting respect for the forces of weather. It would be money well spent to *pay* for a long-distance call.

Even more pilots neglect to obtain a preflight weather briefing because they don't understand the weather information or its importance. Without adequate weather training, they are unable to glean from available information the facts and anticipations needed for their proposed flights. Even if the weather reports and forecasts are interpreted for them, some fail to grasp their operational significance. Perhaps they make flights infrequently and do not ask questions of the briefer simply because they do not have the patience to learn to use weather information effectively.

THE ACCURACY OF AVIATION WEATHER FORECASTS

Pilots should understand the limitations as well as the capabilities of present-day meteorology. Otherwise, the impossible may be requested, while the attainable may be overlooked. The forecaster understands certain principles of atmospheric behavior and has watched this behavior long enough to know how incomplete our knowledge really is. Weather, as a science, is in its infancy despite spectacular progress in recent years. It is not as exact as many other sciences and much less exact than everyone would like. A chemist, for example, can determine not only each ingredient in a substance, but also the weight of each to the nearest ten thousandth of a gram. The weather forecaster is somewhat more effective in predicting the weather than a doctor is in trying to cure a common cold, but still far from perfect.

It is almost as bad for the pilot to have complete faith in weather forecasts as it is for him to have none at all. Pilots who understand both the information given and the limitations of weather observations and forecasts usually are the ones who make the most effective use of the weather service. The safe pilot continually makes a critical analysis of forecasts as he goes along. He knows that weather always is changing and consequently that the older the forecast, the greater the chance that some part of it will be wrong. The weather-wise pilot looks upon a forecast as professional advice rather than as the absolute truth.

Recent studies of the aviation forecasts distributed by FAWS centers indicate the following:

1. Up to 12 hours and even beyond, a forecast of *good* weather (ceiling 3,000 feet or more and visibility 3 miles or greater) is much more likely to be correct than a forecast of conditions below 1,000 feet or below 1 mile.

2. However, for 3 to 4 hours in advance, the probability that *below* VFR conditions will occur is more than 80 percent if *below* VFR is forecast (see fig. 154).

3. Forecasts of single reportable values of ceiling or visibility instead of a range of values imply an accuracy that the present forecasting system does not possess beyond the first 2 or 3 hours of the forecast period.

4. Forecasts of poor flying conditions during the first few hours of the forecast period are most reliable when there is a distinct weather system, such as a front, a trough, precipitation, etc., which can be tracked and forecast, although there is a general tendency to forecast too little bad weather in such circumstances.

5. The weather associated with fast-moving cold fronts and squall lines is the most difficult to forecast accurately.

6. Errors in forecasting the time of occurrence of bad weather are more prevalent than errors

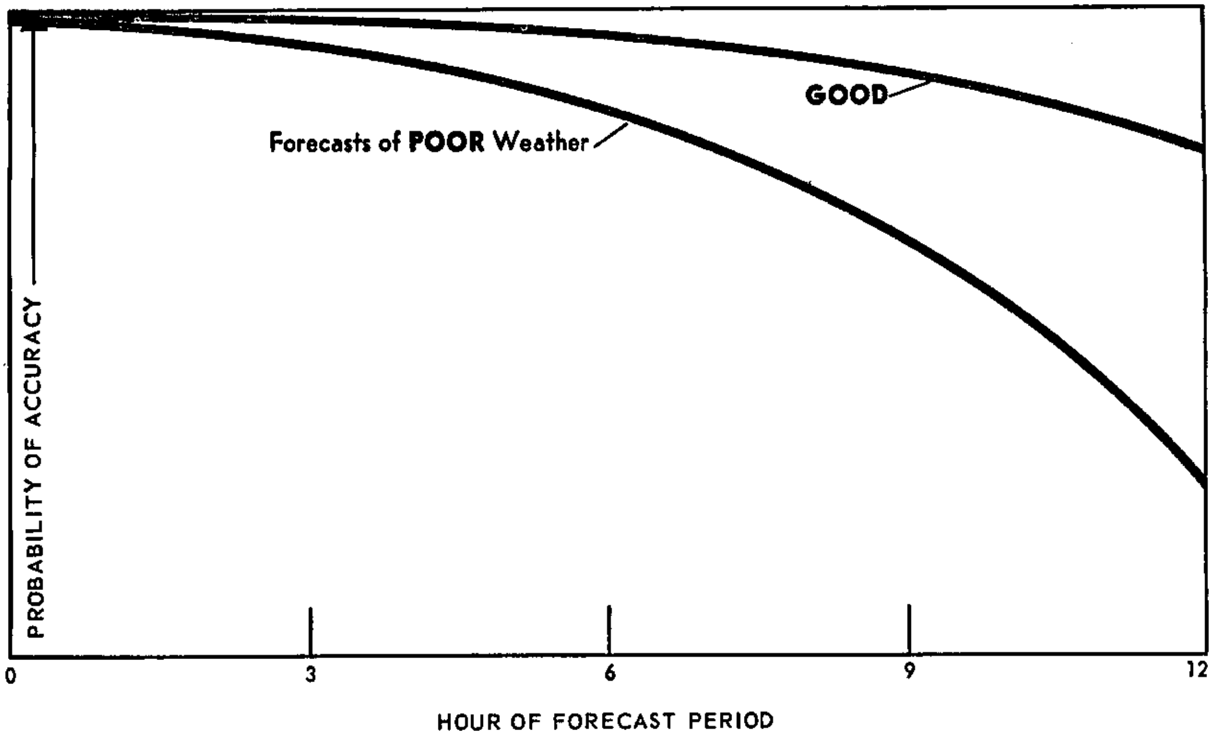


FIGURE 154. Probability of accuracy of forecasts (good versus poor weather).

in forecasting whether it will occur or will not occur within a span of time.

7. Surface visibility is more difficult to forecast than ceiling height, and snow reduces the visibility forecasting problem to one of rather wild guesswork.

Available evidence shows that forecasters CAN predict the following at least 75 percent of the time:

- The passage of fast-moving cold fronts or squall lines within plus or minus 2 hours as much as 10 hours in advance.
- The passage of warm fronts or slow-moving cold fronts within plus or minus 5 hours up to 12 hours in advance.
- The rapid lowering of ceiling below 1,000 feet in prewarm front conditions within plus or minus 200 feet and within plus or minus 4 hours.
- The onset of a thunderstorm 1 or 2 hours in advance if radar is available.
- The time rain or snow will begin within plus or minus 5 hours.
- Rapid deepening of a low pressure center.

Forecasters CANNOT predict the following with an accuracy which satisfies present aviation operational requirements:

- The time freezing rain will begin.
- The location and occurrence of severe or extreme turbulence.
- The location and occurrence of heavy icing.
- The location of the occurrence of a tornado.
- Ceilings of 100 feet or zero before they exist.
- The onset of a thunderstorm which has not yet formed.
- The position of a hurricane center to nearer than 100 miles for more than 12 hours in advance.
- The occurrence of ice fog.

The above indications of what can and cannot be predicted will be found to vary, depending on the climatology and general weather conditions of the area. In general, rare events are more difficult to predict than common events. Weather conditions which have a pronounced diurnal variation, such as the occurrence of nighttime radiation fog or of afternoon convective clouds, can be forecast more reliably than conditions which have small diurnal variation.

Similarly, weather conditions which depend on the interaction of wind flow with mountain ranges, coastal areas, or large bodies of water are more reliably forecast than similar weather conditions which are associated with cyclonic storms moving slowly over flat, uniform terrain.

HELP YOURSELF AND THE WEATHER SERVICE

GET WEATHER-WISE

There probably is no better investment in personal safety, as well as in the safety of others, for the pilot than the effort he spends to increase his knowledge of basic weather principles and to learn to interpret and use the products of the weather service.

In recent years, emphasis has been placed on training weather briefers not only in the weather problems a pilot commonly faces but also in other things, exclusive of actual manipulation of aircraft controls, that the pilot must know. Thus, the weather briefer is a specialist at tailoring weather information to the pilot's particular flight problem. Both he and the FAWS forecaster take familiarization flights in order to better understand and visualize the weather as the pilot sees it.

Similarly, a pilot benefits from knowledge of the weatherman's problems. A pilot can better use the weather service when he understands the service, its products, its capabilities, and its limitations. Although not a magician, the weatherman has a wealth of information in his head and at his finger tips. The fact that most pilots continue to come to the weatherman for information and guidance attests that, despite limitations, the weather service is an essential part of safe and efficient aircraft operations.

Do not omit weather information in your flight planning. It can be the most important part.

CHOOSING YOUR BRIEFING SOURCES

The amount of weather information that pilots need to properly plan their flight varies; it may depend on the conditions set for the flight, the extent to which the aircraft is equipped and is otherwise suitable for coping with adverse weather, and the extent to which the pilot can fly difficult weather situations.

A pilot trained and equipped for instrument flight may not be particularly concerned about ceilings and visibilities other than at his airports of departure, destination, and alternate. His interest otherwise is usually in cloud tops, weather hazards, winds aloft, and surface winds.

The pilot limited to Visual Flight Rules probably needs a more complete weather briefing prior to takeoff than does an instrument-qualified pilot. He should also know whether or not clouds are based high enough to permit visual flight below them at all points along his route, whether or not "VFR on top" flight is feasible, and whether or not flight visibilities are good enough for him to navigate his aircraft by visual reference.

The pilot should know his capabilities and limitations better than anyone else and, as his knowledge of the weatherman's problems grows, his judgment in choosing the method of obtaining weather information for his particular flight operation improves. Obviously, the most effective presentations are those in which the weather briefer is face-to-face with the pilot. There is then an opportunity to clear up certain items which were not caught during the briefing. If facsimile weather charts are available, they assist the pilot in obtaining a plan-view of the weather situation. However, every pilot cannot be served in this manner, and he does not need this much service for every planned flight. For example, if his planned trip is short (250 miles or less), a visit to the weather office may be unnecessary except in marginal or poor weather situations. Often the information contained in recorded weather briefings will fill his needs.

The pilot is encouraged to reserve his personal contacts with the weather briefer, both face-to-face and by unlisted telephone, for those occasions when he is planning a flight of more than 250 miles, or when neither the Pilots' Automatic Telephone Weather Answering System (PATWAS) nor the continuous transcribed weather broadcast (TWEB) answers all of his questions concerning the existing and forecast weather situation. Otherwise he may be consuming needlessly the briefer's time when the briefer could be assisting others in greater need of this service. But, if you do need personal contact with the weatherman, do not give up trying until you have reached him.

It is difficult to say when the weatherman will be readily available for personal contacts because of the wide variance in pilot briefing loads from one briefing office to another. With identical weather situations, weather briefers at one airport might be able to brief every pilot, while at another airport, because of the large number seeking service, perhaps only 10 percent could receive this personalized attention.

Ability to translate the weather products on display (see fig. 125) greatly assists the pilot who desires a briefing in a weather office. If the weather briefer is occupied with priority duties, the informed pilot may brief himself partially if not completely. Self-briefing ability is especially important when departing from an airport where the weather service consists only of a Service A teletypewriter.

BE SPECIFIC WHEN REQUESTING A BRIEFING

When you request a weather briefing, whether face-to-face or by telephone, you greatly assist the briefer and get faster service by telling him the following:

1. That you are a pilot. (Many requests for weather information are not related to aviation. Also airline *passengers* often inquire about flying weather.)
2. The type of aircraft you are planning to fly. (Light single engine, high performance multiengine, and jets all present different briefing problems.)
3. Your destination.
4. Your estimated departure time.
5. Whether or not you can go IFR.

GET A COMPLETE WEATHER BRIEFING

If a telephone or face-to-face briefing is considered necessary and you have given the information listed above, the briefing will be incomplete unless it contains all of the following information:

1. Weather synopsis (positions of lows, fronts, ridges, etc.).
2. Current weather conditions.
3. Forecast weather conditions.
4. Alternate routes (if necessary).
5. Hazardous weather.
6. *Forecast* winds aloft.

If you don't get all this information, ask for it. However, you very likely will get a complete briefing because the above items are part of the briefer's checklist. It will help if you let him finish his presentation before asking questions.

If facsimile charts are available, you should see the following items as a minimum:

- The Surface Weather Chart and the Surface Prognostic Chart for present and forecast positions of highs, lows, fronts, and squall lines.
- The Weather Depiction Chart to see the general areas where ceilings and visibilities have been poor, and to relate these low ceilings and visibilities to the major features on the surface weather chart.
- The Radar Summary Chart for a display of weather hazards that might not be available otherwise. This chart locates and describes intensities of thunderstorm areas and includes current severe weather forecasts.
- Winds Aloft Charts or Constant Pressure Charts for a knowledge of the current general wind flow for altitudes of concern.
- Latest Aviation Weather Reports, Radar Observations, and Pilot Reports for your route to bring up-to-date the picture of current weather conditions.
- Area Forecasts covering all of your proposed route.
- Terminal Forecasts for your destination and at least one alternate.
- Winds Aloft Forecasts for the expected wind conditions over your route and at your altitude (s). The best altitude (s) and route (s) in most cases are determined by expected wind conditions.

- Any In-Flight Weather Advisories in effect for the route (s) and altitude (s) of concern.

HAVE AN ALTERNATE COURSE OF ACTION

There are seldom enough observations to describe in detail the weather over every portion of an air route. Also, pilots sometimes encounter weather different from that forecast because of forecast limitations. Therefore, in applying the weather reports and forecasts to his flight and in analyzing the weather as the flight progresses, the pilot always should have an alternate course of action in mind in case the weather goes "sour." Also he should know alternate weather possibilities in addition to the specific weather forecast. Only then can important deviations from the expected weather be recognized in time for action. For example, satisfactory weather conditions are expected for a certain flight, but there is a chance that approaching thunderstorms may reach the terminal before the flight is completed. If the direction of movement of the thunderstorms is known, the pilot knows his best alternate action in case they move faster than anticipated.

The old adage "to be forewarned is to be forearmed" also applies to flying weather. The importance of having an alternate course of action in mind in the event unsuitable weather develops can hardly be overemphasized. An "alternate action" may be more than a change in course; it may be a change in flight altitude to avoid icing or turbulence, a 180° turn, and/or a landing at the first suitable airport to await improvement in the weather. Weatherwise, "alternate action" is any change in a flight plan made to avoid or minimize the effects of adverse weather.

Oftentimes bad weather can be circumnavigated. But this is not always feasible, especially for short flights. Many storms blanket several States or more, making alternate routes impractical or even impossible.

SEND PILOT REPORTS

With his vantage point in the sky, the airborne pilot who fails to report what he sees is withholding information which could be used to great advantage by weathermen and other pilots. Aviation Weather Reports, while essential, are "spot" observations. Sometimes the weather may be significantly different in the area *between* the observing stations than it is *at* the stations.

As mentioned in an earlier chapter, the pilot actually is a part of the nation's aviation weather system. Since he fills a gap in the observational network immediately after becoming airborne, he should feel a responsibility for reporting what he sees and encounters. In many situations, a wise pilot would not consider departing for his destination without a thorough briefing on the weather. But his briefing will be more effective if other pilots have added their knowledge of the weather picture to other available data. Imagine, for example, an airline pilot departing from Honolulu on a nonstop flight to Tokyo without knowledge of existing and expected winds enroute and the expected terminal conditions at Tokyo at the time of his arrival there. How do airline operations personnel know how much fuel the aircraft should carry? How do they determine its maximum allowable gross weight (including passengers and baggage)? How do they decide on what terminals should be used for alternates in case of unforeseen difficulty enroute and make other decisions necessary for safe and efficient flight operations? On this particular route, as well as on many other ocean routes, there are few scheduled upper air observations, and the weatherman would have to do a lot of guessing were it not for the wind and weather reports made by pilots flying the route.

The accuracy of weather forecasts is dependent largely upon the quantity, representativeness, and timeliness of the data available to the forecaster. Reports of weather conditions verifying a prediction are equally as valuable to the weather service as those indicating conditions which were not expected.

Pilots have a moral responsibility to other pilots to report the weather that they see. Perhaps some pilots have sent reports only to find upon landing that the information was not given complete distribution. Admittedly, the collection and distribution system for PIREPS isn't perfect, but it has been improved considerably in recent years. Reports from pilots are given the widest possible distribution and always are posted for ready reference in briefing offices.

GET TO KNOW THE WEATHERMAN

Discussions and exchanges of ideas between pilots and weather briefers are mutually profitable. For example, perhaps the pilot can suggest improvements in weather service within the capabilities of the weather science and without additional expense. Through discussions, they learn more about each other's problems, and each keeps abreast of new developments in the other's field of specialization.

SOME ADDITIONAL POINTERS

Following are some additional ways in which the pilot can make more effective use of the weather service as well as help it:

1. Don't try to play one forecaster against another by shopping for forecasts.
2. Don't try to influence the forecaster or briefer into saying the weather will be better than he actually thinks it will be.
3. Don't ask that a long string of Aviation Weather Reports be read to you over the telephone, especially when calling the second or third time. You are needlessly burdening the weather briefer because his more general answers to your questions are accounting for the latest available information.
4. Don't try to make your own forecast unless you are a qualified forecaster; leave that job to the "pros".
5. Don't try to get the briefer to make *your* decision of whether or not you will fly; only *you* can make that decision.
6. Fix limits of weather conditions beyond which you will not fly—and stick with them.
7. Even if you are instrument-rated, beware of situations which are or threaten to be borderline between VFR and IFR. These are the situations that cause most weather-connected aircraft accidents.
8. If you fly mostly over the same area from trip to trip, thoroughly familiarize yourself with the detailed geography of the area and the weather reporting stations and FAA navigational aids in that area.
9. Obtain maps of the area covered by the nearest transmission point of the continuous transcribed weather broadcast and PATWAS. Spot the weather systems and expected ceilings and visibilities on the map. Get a similar map for any part of the country in which you intend to fly.
10. Don't expect the weather associated with a front or other feature on the weather chart to look exactly like an illustration of one you saw in a book—no two weather situations are exactly alike.
11. When in-flight, monitor broadcasts for hourly Aviation Weather Reports, changes in forecasts, and In-Flight Weather Advisories. Be prepared for unforecast changes in weather to crop up and report what you see.
12. Familiarize yourself with average and extreme weather conditions by season over your area. A large amount of climatological information has been published by the Weather Bureau and is available through the Superintendent of Documents, Washington, D.C., at nominal cost. Also, you can talk it over with your local weatherman.
13. Use the weather; don't fight it.

Part THREE

SUPPLEMENTARY LESSONS ON WEATHER

Chapter 19
HIGH ALTITUDE WEATHER

As man flies higher and higher, he encounters atmospheric phenomena which he must understand in order to fly safely at these altitudes. Commercial and military jet aircraft, of course, have been operating at high altitudes for a number of years. Now, business executives, in their quest for speed, are turning more and more to turbo-prop and small jet aircraft. Even some of the so-called "light twins" of the conventional type are equipped for operation in the upper troposphere and lower stratosphere. Pilots flying at these altitudes are confronted with such atmospheric phenomena as the tropopause, the jet stream, clear air turbulence, and others.

THE TROPOPAUSE

The tropopause, the boundary between the troposphere and the stratosphere, is found at altitudes of 50,000 to 60,000 feet over the Tropics, contrasted to altitudes about half as high over the poles. Sometimes the boundary extends unbroken from the Tropics to the poles, but a

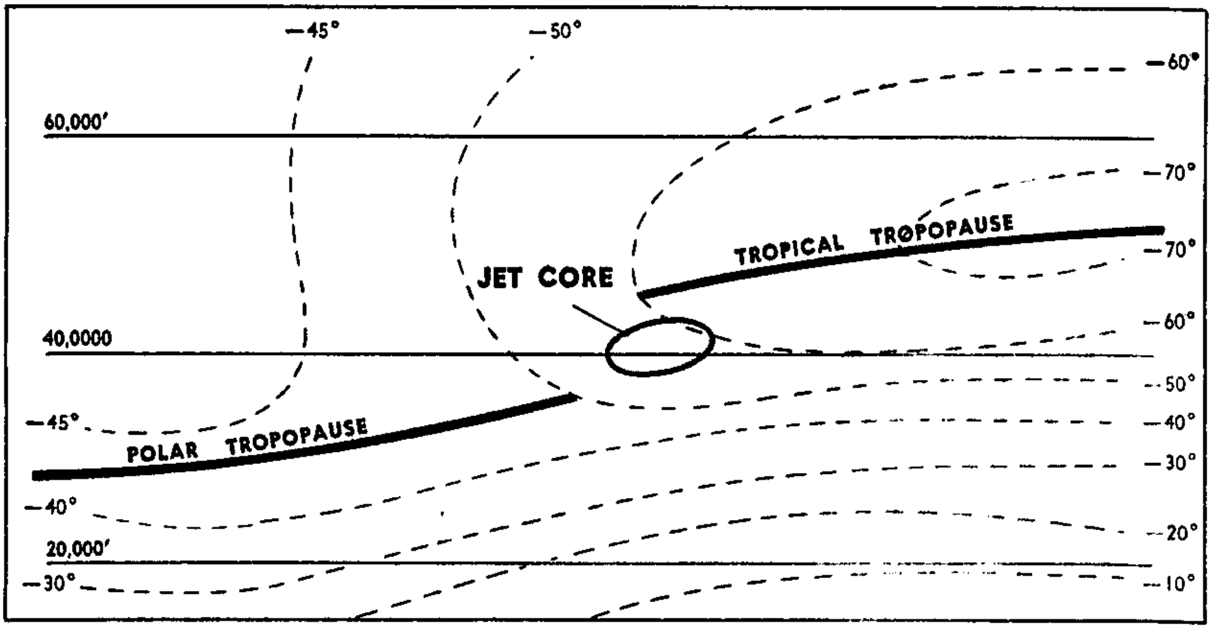


FIGURE 155. The polar tropopause and the tropical tropopause.

break in the tropopause in midlatitudes is the more usual situation, with both the polar and the tropical tropopauses lying in gradual slopes and sometimes overlapping for a considerable distance.

Because of the frequent presence of strong wind shears in the vicinity of the tropopause, this boundary zone often is a region of turbulence. Since the zone is frequently devoid of clouds, this condition commonly is classified as "clear air turbulence."

The strongest jet streams usually are found near the tropopause, particularly in the break region between the polar tropopause and the tropical tropopause (see fig. 155).

THE JET STREAM

The jet stream is a narrow, shallow, meandering river of strong winds which usually extends around the temperate zone of the earth (see fig. 156), but which also may be found in the subtropics. It follows a wavelike pattern as a part of the general wind flow, and it is located in regions where there are large horizontal differences in temperature between warm and cold air masses. A jet stream is considered to exist whenever winds of 50 knots or stronger, embedded in the high tropospheric or lower stratospheric general wind flow, are concentrated in a band at least 300 nautical miles long. Wind speeds in the jet stream sometimes may reach 300 knots but generally are between 100 and 150 knots. Since the jet stream, like the polar front (ch. 10), is stronger at some places than at others, it rarely encircles the entire hemisphere as a continuous river of air. More frequently it is found in segments from 1,000 to 3,000 miles in length, 100 to 400 miles in width, and 3,000 to 7,000 feet in thickness (see fig. 157).

The main jet stream appears to have a life cycle of formation, intensification, movement, and dissipation related to the polar front. Its orientation, location, zones of maximum wind, and thickness generally vary with latitude, longitude, altitude, and time. In middle and high latitudes, the strength of jet streams is greater in winter than in summer. The mean position of the jet stream shifts south in winter and north in summer with the seasonal migration of the polar front. As the jet stream moves southward, its core rises to a higher altitude and, on the aver-

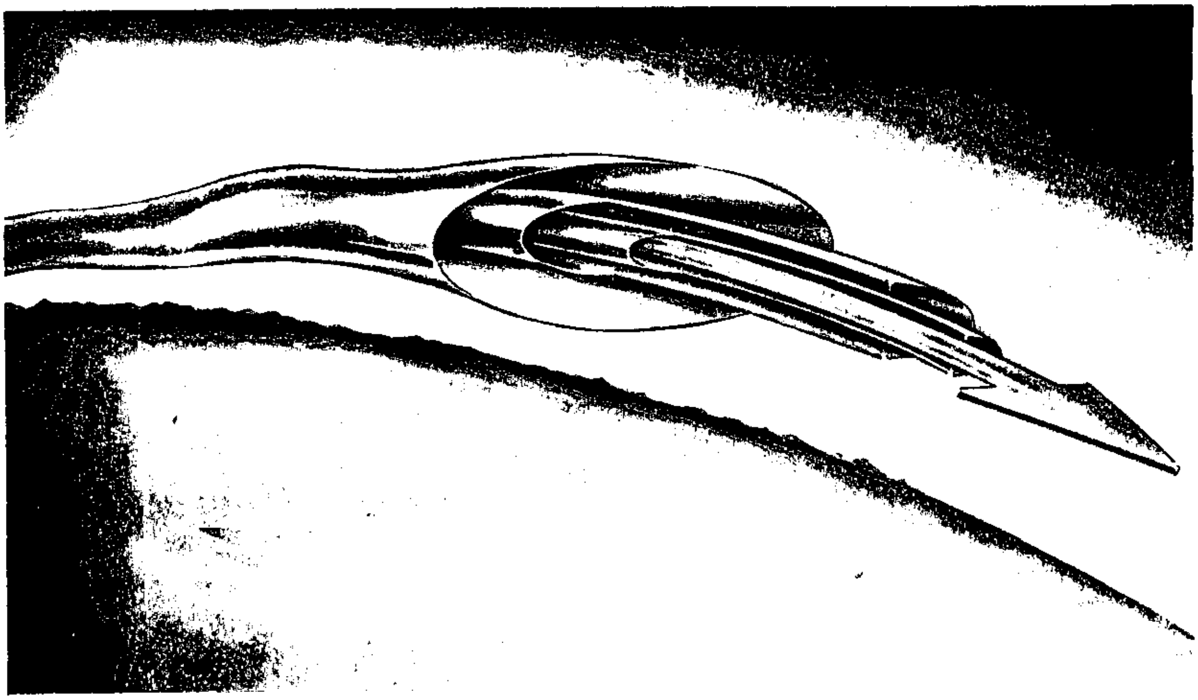


FIGURE 156. The jet stream.

age, its speed increases. Winter jet streams often are found as far south as the 20th parallel. The core of strongest winds in the jet stream generally is found between 25,000 and 40,000 feet, depending on latitude and season.

In figure 158, notice that the highest wind speeds in the polar-front jet stream are found about 5,000 feet below the tropical tropopause and near the end of the polar tropopause. Also notice that the rate of decrease of wind speed is considerably greater on the polar side than on the equatorial side—that is, the magnitude of the wind shear is greater on the polar side than on the equatorial side.

There may be two or more jet streams in existence at the same time. For example, as illustrated in figure 159, one jet stream is over Canada and an equally well-defined one, known as the "subtropical jet," is over the southern United States. Figure 160 shows typical vertical profiles of wind speeds over midlatitude stations.

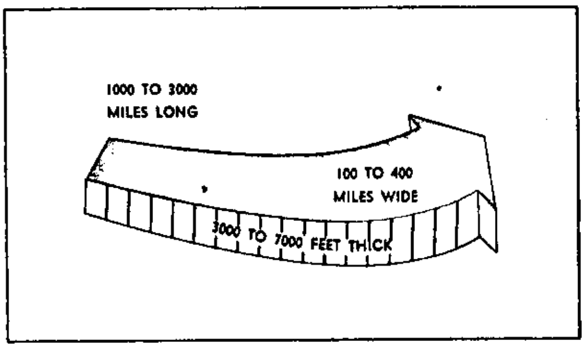


FIGURE. 157. Size of a jet stream segment.

CLEAR AIR TURBULENCE

The term "clear air turbulence" is commonly used to denote the rough, washboardlike bumpiness which sometimes buffets an airplane in a cloudless sky. This bumpiness may be of sufficient intensity to cause serious stresses on the aircraft and physical discomfort to its passengers, especially since the rough air occurs without any visual warning.

Chapter 7 indicated that clear air turbulence can be present at any altitude. However, this

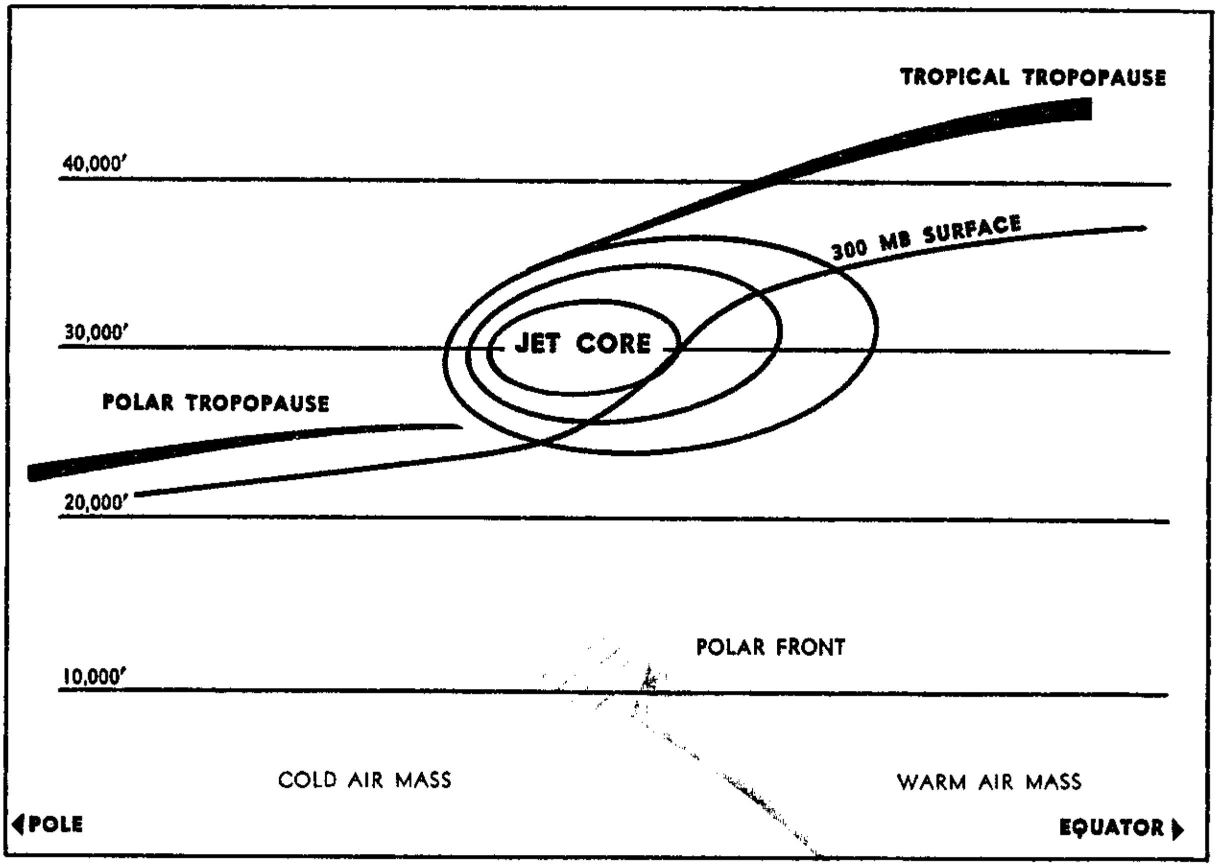


FIGURE 158. Jet winds as related to the polar and tropical tropopauses.

phenomenon is found most frequently at higher altitudes in association with a marked change of wind speed with height (vertical wind shear) and/or in the horizontal (horizontal wind shear). These conditions most often occur in and near the maximum wind speed centers that move along the jet stream. Clear air turbulence is related to the position of the jet stream, and evidence exists that the maximum occurrence of severe clear air turbulence in the vicinity of the polar-front jet streams is on the cold air (polar) side near the polar tropopause and below the jet core level (see fig. 161).

The occurrence of clear air turbulence may extend to high levels and may be associated with other features of the atmosphere, such as the turbulence that is encountered near the periphery of lows aloft, at and below the tropopause, in the vicinity of troughs, or over mountains and hills, particularly if a mountain wave exists (see ch. 7). Areas of clear air turbulence often are isolated with thicknesses of less than 2,000 feet.

CONDENSATION TRAILS

A condensation trail, popularly contracted to "contrail," is generally defined as a cloud-like streamer which frequently is generated in the wake of aircraft flying in clear, cold, humid air. Two distinct types are observed—exhaust trails and aerodynamic trails. "Distrails," contracted from dissipation trails, are produced entirely differently from exhaust and aerodynamic trails; they will be discussed briefly.

EXHAUST CONTRAILS

This type of contrail is formed by the addition to the atmosphere of sufficient water vapor

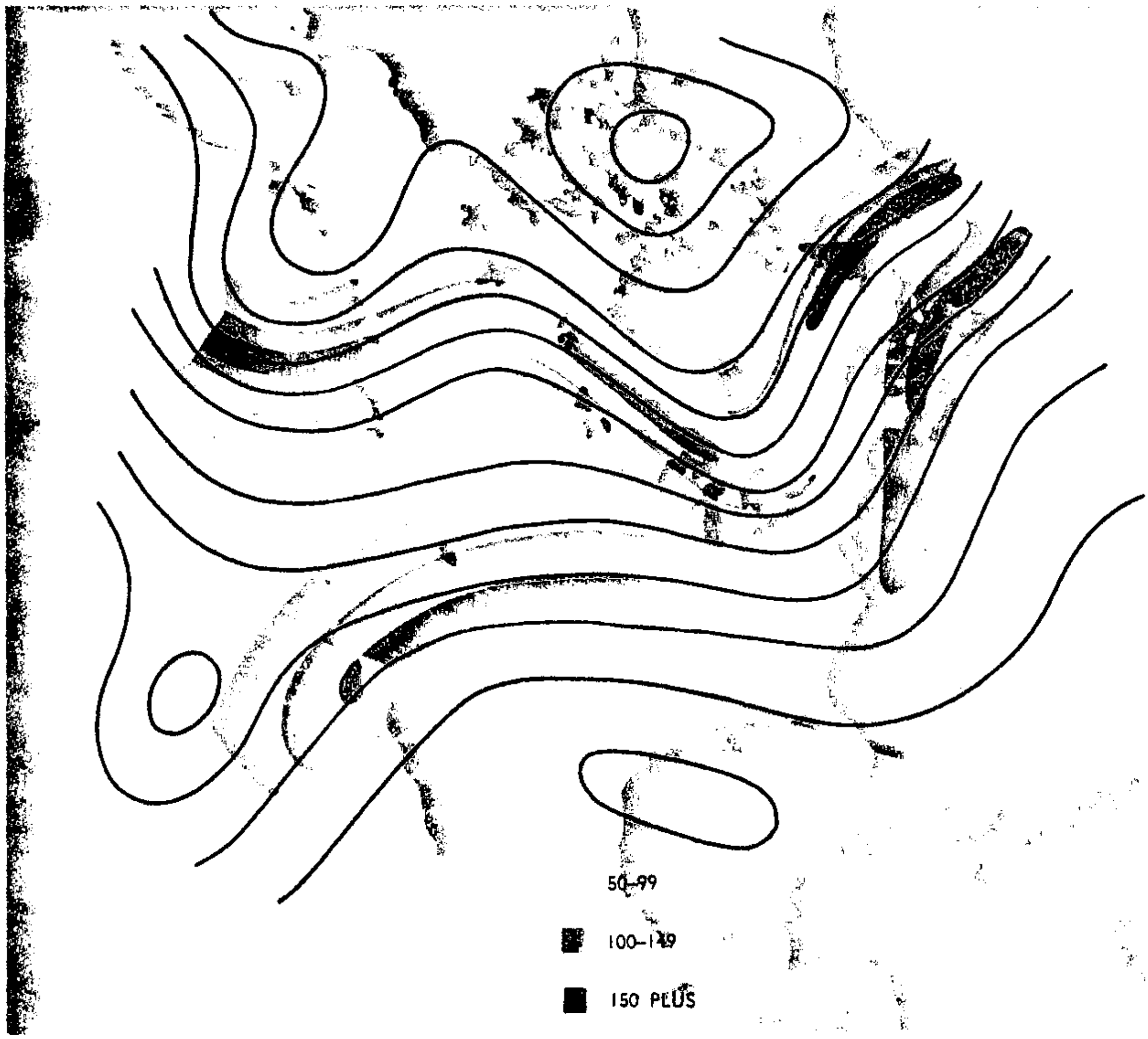


FIGURE 159. Multiple jet streams.

from aircraft exhaust gases to cause saturation or supersaturation of the air. Since heat is also added to the atmosphere in the wake of an aircraft, the addition of water vapor must be of such magnitude that it saturates or supersaturates the atmosphere in spite of the added heat.

There is evidence to support the idea that the nuclei which are necessary for condensation or sublimation may also be donated to the atmosphere in the exhaust gases of aircraft engines, further aiding the contrail formation process. These nuclei are relatively large, and recent experiments have revealed that visible exhaust contrails may be prevented by adding very minute nuclei material (dust, for example) to the air. Condensation and sublimation on these smaller nuclei result in contrail particles too small to be visible.

AERODYNAMIC CONTRAILS

In air that is clear and almost saturated, the aerodynamic pressure reduction that accompanies the flow of air around propeller tips, wing tips, and the like, can cool the air enough to bring it to saturation, and, hence, to condensation. This type of trail usually is neither as dense nor as persistent as exhaust trails.

Aerodynamic trails, as well as exhaust trails, are most likely to form in January and least likely in July. Neither present any aircraft op-

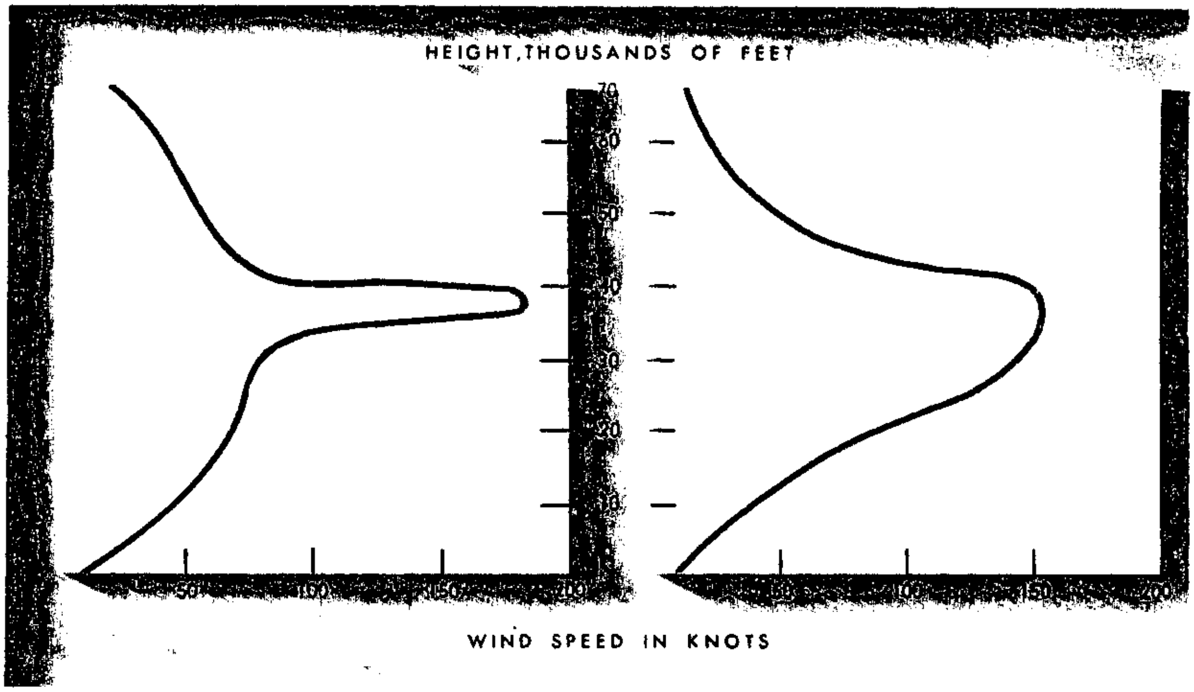


FIGURE 160. Vertical profiles of wind speeds.

erational problems. Contrails create a problem only when they reveal the presence of aircraft attempting to fly undetected, or when they prevent use of the "see and be seen" concept in VFR operations.

DISSIPATION TRAILS (DISTRAILS)

This term applies to a rift in clouds caused by the heat of exhaust gases from an aircraft flying in a thin cloud layer. The exhaust gases sometimes warm the air to the extent that it is no longer saturated, and that portion of the cloud which is affected evaporates. The cloud must be both thin and relatively warm for a distrail to exist; therefore, they are not commonly seen.

HAZE LAYERS

Haze layers not visible to ground observers frequently exist in the upper troposphere. These layers do not appear to be as dense as ordinary cirrus clouds. The tops of these layers are more definite than their bases, and the visibility above is excellent. However, visibility within the haze sometimes is reduced to zero, depending on the position of the sun relative to the pilot's line of sight. These haze layers at high levels occur in stagnant air masses; they are rare in fresh polar outbreaks.

Cirrus haze is common in the Arctic in winter, sometimes extending from the surface to the tropopause.

CANOPY STATIC

Canopy static, similar to the precipitation static sometimes encountered at lower levels, is produced as a result of solid particles brushing against plastic-covered aircraft surfaces. The discharge of generated static electricity results in a noisy disturbance which reduces radio recep-

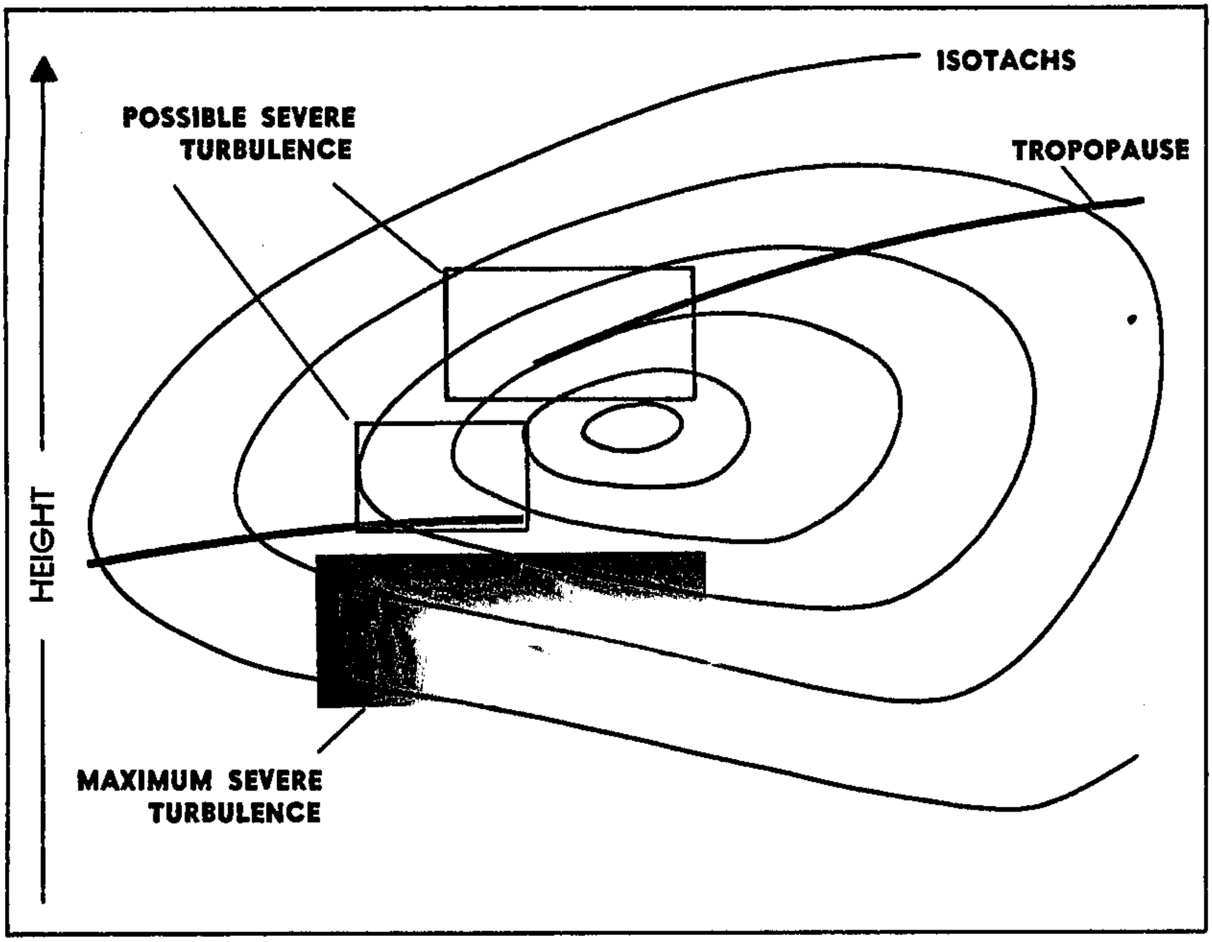


FIGURE 161. Cross section of a jet stream with related turbulent areas.

tion. This process can occur in such rapid succession that it seems to be a continuous disturbance. Since dust and ice crystals in cirrus clouds are the primary producers of canopy static, it usually can be eliminated by changing altitude.

ICING CONDITIONS

Although not as common or as extreme as at low altitudes, icing can occur in flight at high altitudes. It can form very quickly on the airfoil and exposed parts of jet engines. Icing at high altitudes is associated with tops of cumulus buildups, anvils, and even some detached cirrus. Clouds over mountain areas are more apt to contain liquid water and, hence, cause icing at high levels.

Structural icing at high altitudes usually is of the rime type, although clear ice is possible. Usually, it can be eliminated by changing altitude or by varying course to avoid clouds.

Anti-icing systems currently in use are not always adequate protection from all icing conditions. Chapter 12 provides further details on aircraft icing.

THUNDERSTORMS

Chapter 11 mentioned that thunderstorms commonly penetrate the upper troposphere and sometimes the stratosphere. They should be given a wide berth horizontally and vertically because they are capable of producing extreme turbulence, heavy hail, and heavy precipitation. Turbulence, in particular, may be encountered in clear air for a considerable distance horizontally and vertically from growing thunderstorms.

Chapter 20
ARCTIC WEATHER

The Arctic is rapidly becoming the aerial crossroads for transportation of people between major cities of the world. This trend has grown with the increase in altitude and distance capability of aircraft. Great Circle Arctic routes are shorter than the familiar ocean routes between many major cities and, at high altitudes, offer considerably better flying weather.

Aviation in the Arctic is not confined to aircraft which fly long distances and at high altitudes. Pilots of oil exploration companies and those on geological, botanical, zoological, and glaciological surveys, on ice reconnaissance missions, and other scientific explorations are constantly probing the Arctic wilderness; added to these are the "bush" pilots. Further, support for remote native settlements, weather stations, and military installations add to the air activity in the far north. The majority of these pilots must contend with the weather "downstairs," where Arctic weather is at its worst. Weather conditions in terminal areas are sometimes very good but often present serious hazards to aircraft operations. Restricted visibility caused by inclement weather and poor depth perception in "whiteouts" often make takeoffs and landings difficult if not outright hazardous; iced runways make special flight techniques necessary; and mechanical turbulence becomes a problem when the surface wind is strong. These and other flight problems will be examined after a discussion of some general Arctic features.

ARCTIC PHYSICAL GEOGRAPHY AND CLIMATIC INFLUENCES

The Arctic, strictly speaking, is the region which lies north of the Arctic Circle (66½° latitude) (see fig. 162). However, in this chapter additional information is given on Alaskan weather even though much of our 49th State lies south of the Arctic Circle.

The newcomer to the Arctic is staggered by the awesome barrenness of the land, by the immensity of the region throughout, and by the terrible fury of the wind, blowing snow, and bitter cold. The veteran, however, takes all of these as a matter of course, and looks instead to

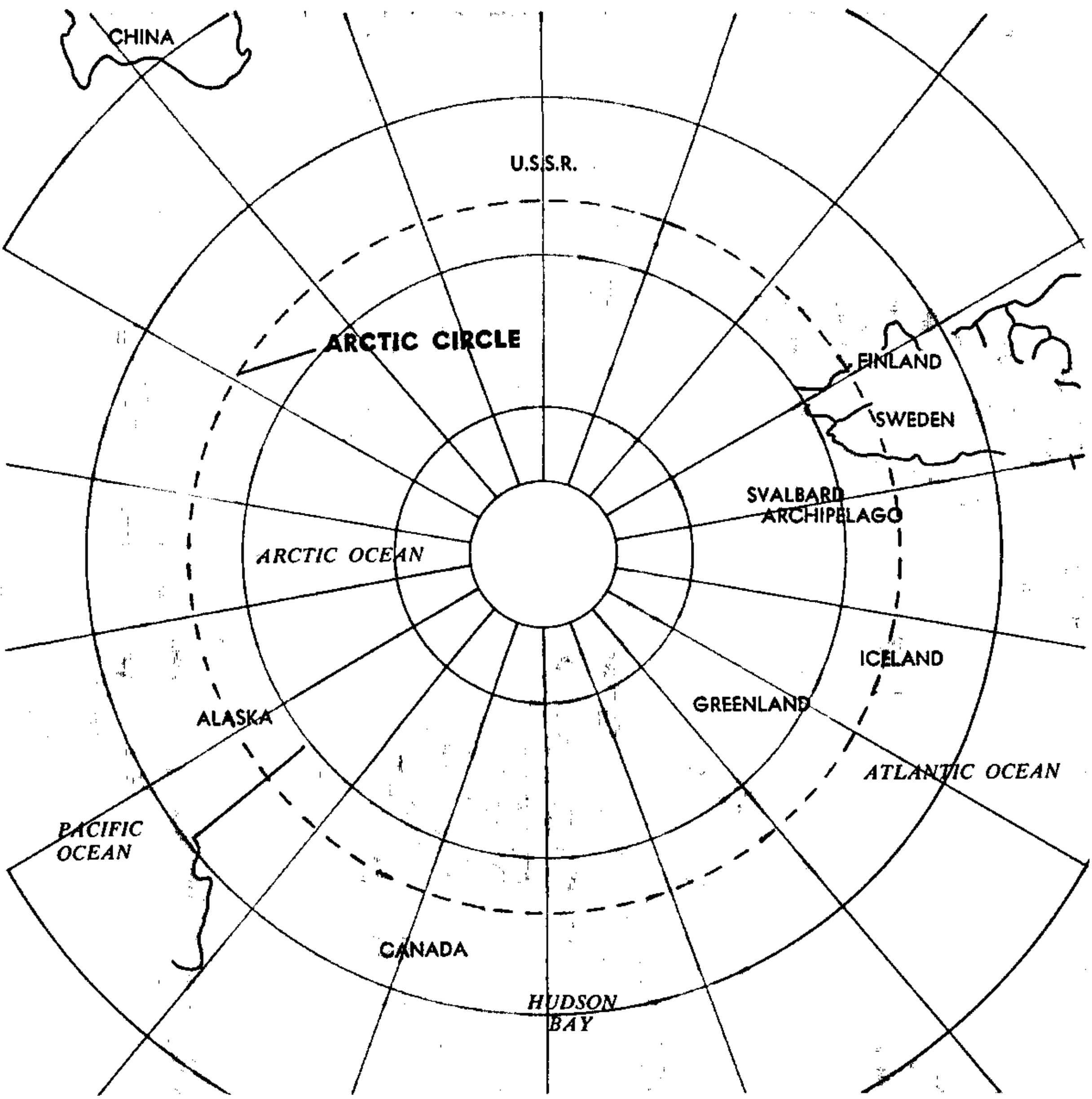


FIGURE 162. The Arctic.

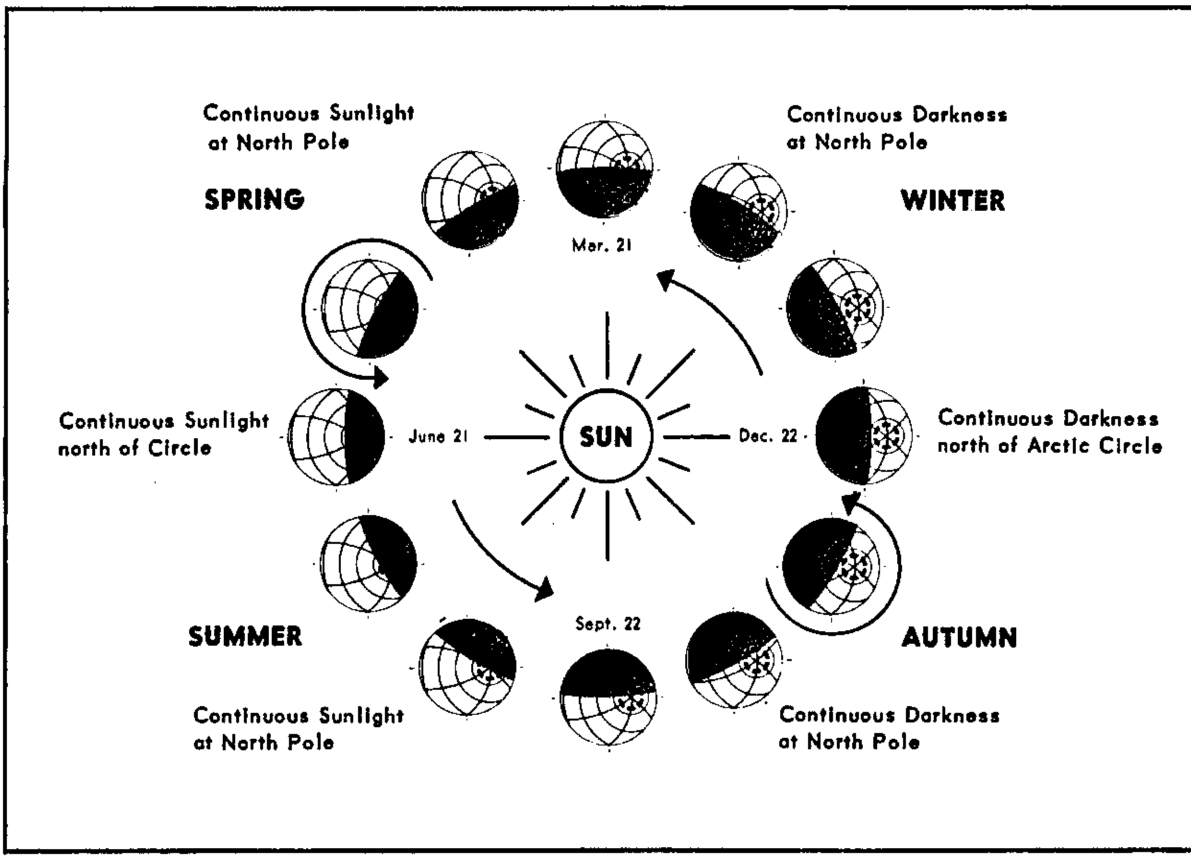


FIGURE 163. Sunlight of the Northern Hemisphere.

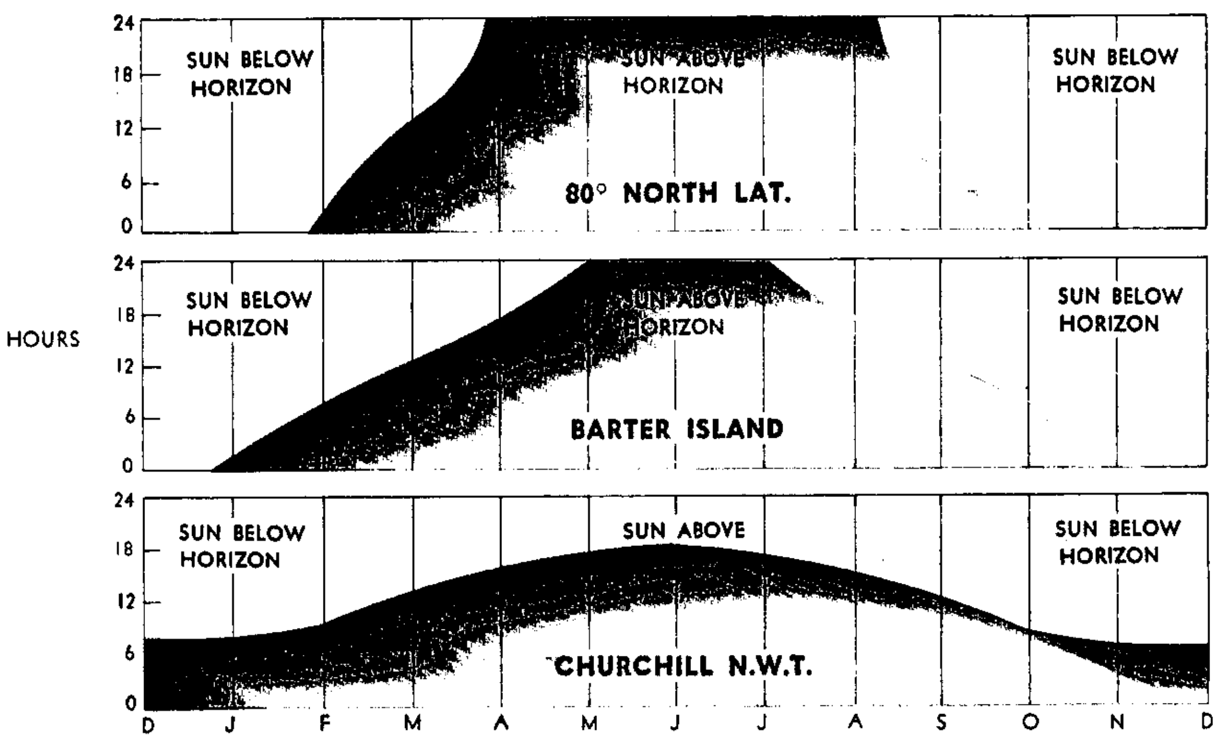


FIGURE 164. Number of hours the sun is above or below the horizon.

the glory of the aurora-filled winter nights, to the short summer with migratory bird life, and an occasional herd of caribou. It is not unusual to enjoy a week or two of cloudless, sunny, warm days with temperatures characteristic of the middle latitudes. This is the Arctic on its best behavior.

The climate of any area is largely determined by the amount of energy it receives from the sun. The energy which the area obtains from the sun depends upon (1) the duration of sunlight, (2) the angle of incidence of the sun's rays, and (3) the average cloud cover. The greatest amount of heat energy from the sun reaches the earth in the equatorial region, while the amount decreases toward the poles; the amount of energy also varies from season to season. As shown in figure 163, much of the Arctic receives little or no direct heat from the sun during the winter. Notice in figure 164 how much more sunlight is received toward the south.

The climate of a region is not completely determined by energy from the sun. If this were the case, there would be no variations in climate from one place to another at the same latitude. The very definite variations are attributed to (1)

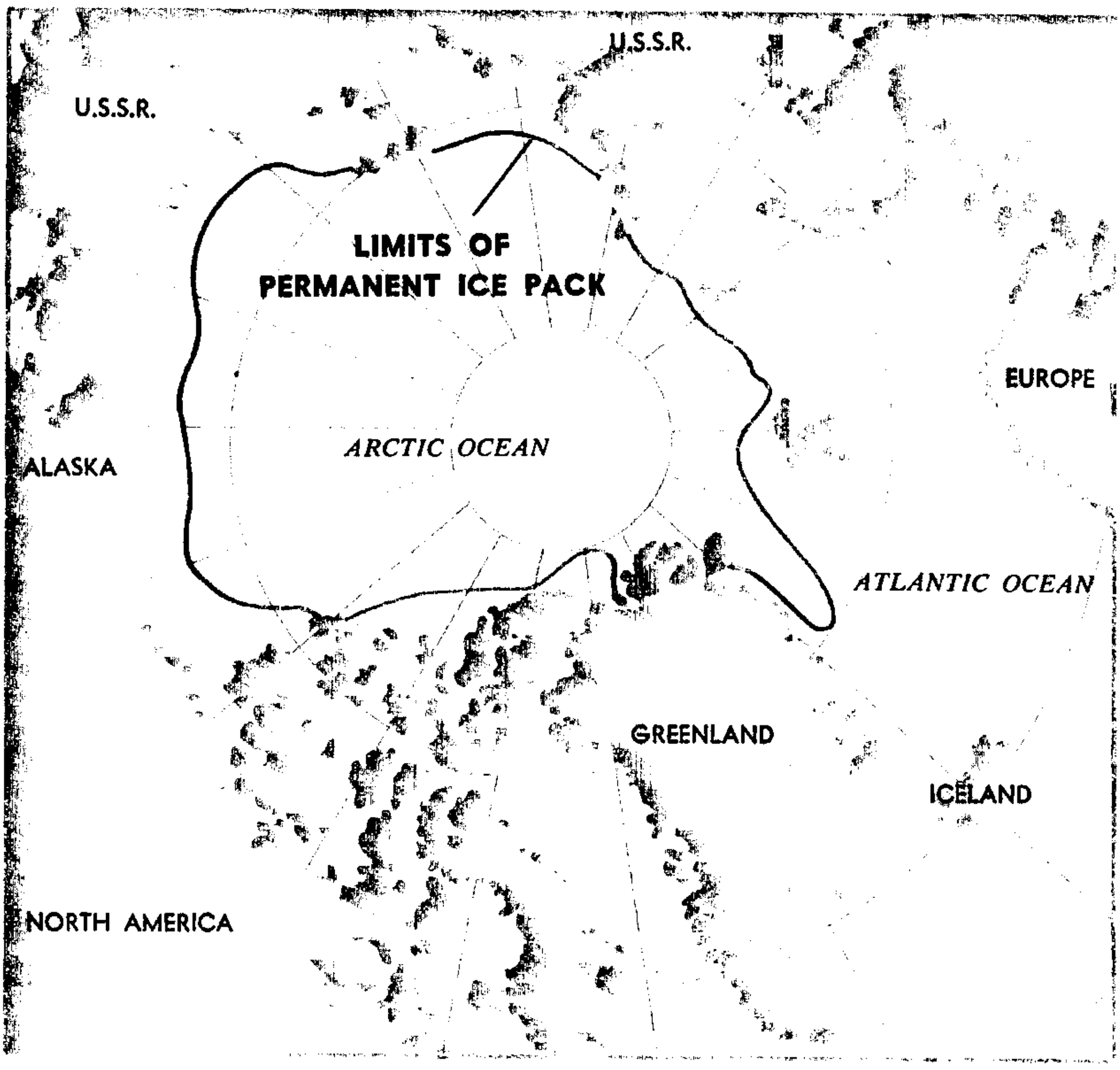


FIGURE 165. The permanent ice pack.

the distribution of water and land, (2) the physical features of the land, (3) ocean currents, and (4) differing heat losses of various land and water surfaces through radiation. Figure 162 shows the water and land distribution in the Arctic.

WATER FEATURES

The Arctic Ocean and parts of the North Atlantic and North Pacific Oceans comprise the principal water areas of the Arctic. A large portion of the water area encircling the Pole is in the solid state (ice) for a considerable depth throughout the year. Known as the *permanent* ice pack (fig. 165), this ice sheet is composed of floes and pressure ridges of ice; in summer, it is crisscrossed by cracks and open leads. Affected by wind, tides, and currents, it is continually shifting with a general circumpolar clockwise movement throughout the Arctic Basin. As shown in the illustration, this ice cover becomes

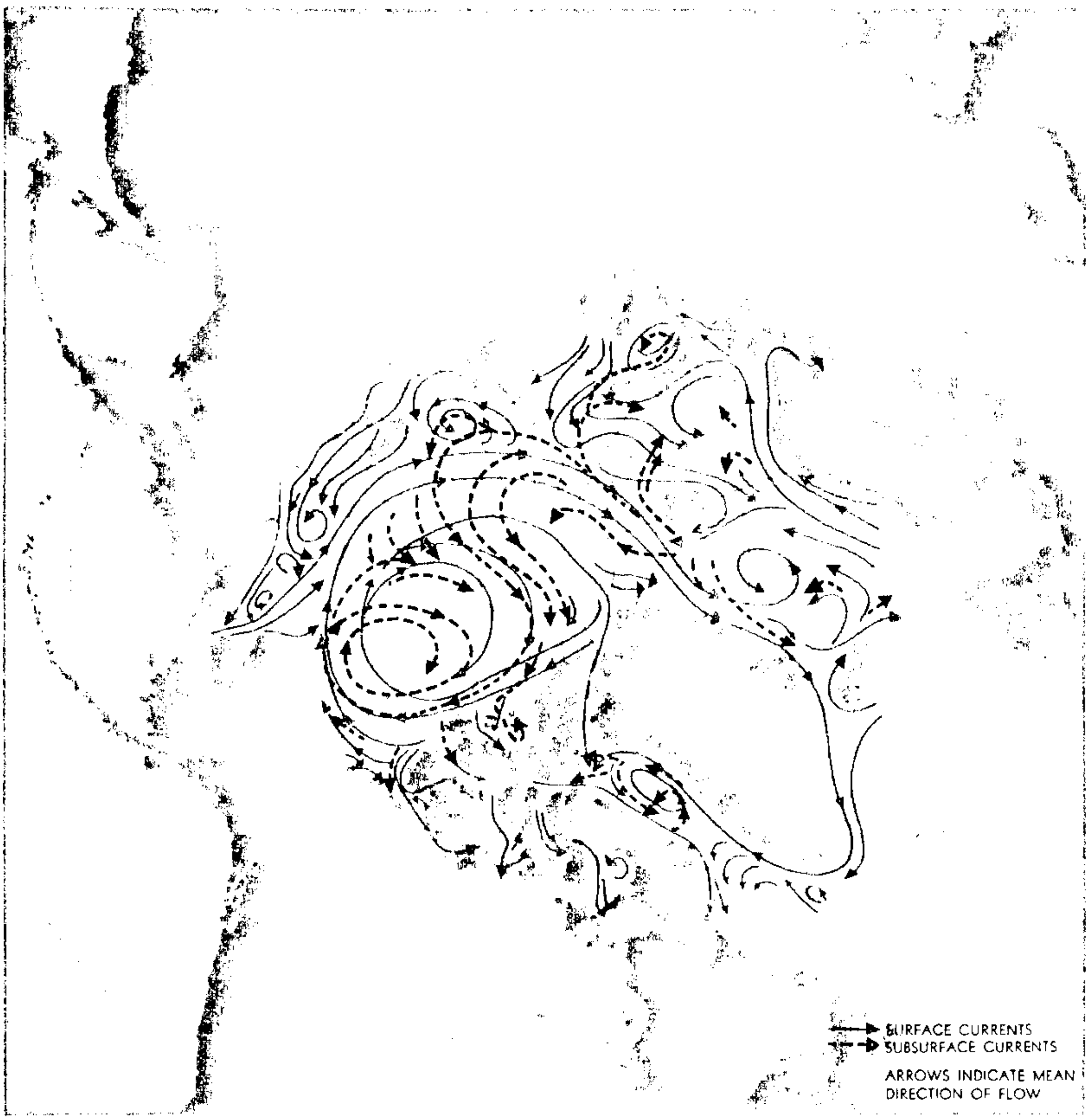


FIGURE 166. Arctic ocean currents.

larger during the winter months. Even when ice-covered, the water bodies act as temperature moderators, since heat penetrates upward through the ice. Thus, the vast Arctic Ocean Basin is warmer than would normally be expected. Temperatures also are influenced by ocean currents. The more prominent currents are shown in figure 166.

LAND FEATURES

Land areas in the Arctic (fig. 162) include the northern portions of Europe and Asia (Eurasia), the Canadian Archipelago, most of Greenland, and the Svalbard Archipelago. As opposed to the large water bodies, the larger land areas tend to show direct results of the extremes of seasonal heating and cooling by their large seasonal temperature variations.

The Arctic mountain ranges of Siberia and North America contribute to the climatic and air mass characteristics of the region, since these ranges are effective barriers to the movement of air. During periods of weak wind flow, air is blocked by the mountains and becomes more or less stagnant. It is during these periods that the air acquires the temperature and moisture characteristics of the underlying surface. Thus, Arctic areas are air mass source regions; they are particularly effective as source regions during the winter, when the surface is covered with ice and snow, and strong northwest winds aloft bring repeated invasions of cold air into midlatitudes.

Greenland covers an area of more than 1,000,000 square miles and is a formidable barrier to air movement. Rugged mountain ranges and glaciers line most of its outer perimeter, with rugged, saw-toothed peaks extending to over 9,000 feet. A massive plateaulike icecap covers the greater part of Greenland, gradually reaching an altitude of nearly 10,000 feet in the heart of the interior. Its north-south orientation of approximately 1,600 miles lies in the way of the general west to east flow of wind and weather. Thus, in combination with the water masses on either side, this barrier acts as a graveyard for low pressure areas to the west and a cradle for new lows to generate in the east. Deep low pressure centers move northward along Greenland's west coast and result, before beginning to degenerate, in some of the largest rates of falling pressure recorded anywhere in the world, other than in association with hurricanes and tornadoes.

HEAT LOSS BY RADIATION

Much of the Arctic receives little or no sunlight in winter and, during the prolonged night, there is a continual loss of heat by radiation. Snow surfaces are very effective radiators of heat, contributing significantly to the bitter coldness of the Arctic winter. This radiative heat loss is considered to be a climatic influence rather than a weather condition because it is a prolonged and continual phenomenon each winter.

GENERAL WEATHER CONDITIONS IN THE ARCTIC

AIR MASSES

In winter, air masses form over the expanded ice pack and adjoining snow-covered land areas. (Observe the Arctic wasteland as illustrated in fig. 167.) These air masses are characterized by very cold surface air, low humidity and a pronounced temperature inversion in the low levels. Since the amount of moisture that air can hold is directly dependent upon temperature, the cold Arctic air is very dry. On some occasions in winter, air masses form over the unfrozen oceans. These air masses do not have low-level temperature inversions because of the much warmer surface temperatures. But, for the same reason, they do have greater moisture content, accounting for most of the infrequent wintertime cloudiness and precipitation in the Arctic.

During the summer, distinction between air masses almost disappears because of the nearly uniform surface conditions over the Arctic and subpolar regions. Several inches of the permafrost thaw during the period of continual daylight; some of the snow melts from the glaciers and pack ice; the ice melts in the numerous ponds and lakes; and the open water areas of the Polar Basin increase markedly. Thus, the area becomes more humid, relatively mild, and semimaritime in character. Temperatures are usu-

FIGURE 167. Typical Arctic frozen oceans, snow-covered ground, and mountain peaks.

ally between freezing and 50° F. Occasional strong disturbances from the south raise temperatures to higher values for short periods. Daily extremes, differences from one place to another, or from day-to-day are slight. The largest amount of cloudiness and precipitation occurs during these months.

FRONTS

A front in the Arctic has much the same weather pattern as that found with midlatitude fronts, except that middle and high clouds are generally much lower, and precipitation is usually in the form of snow. Surface winds are usually strongest during and just after a frontal passage, often creating such hazards as blowing snow and mechanical turbulence.

TEMPERATURES

The Arctic is usually very cold in winter, but even then, on occasions, some areas are surprisingly warm. This occurs when deep low pressure systems move into the area, coupled with heating by compression of air (foehn) as it flows down mountain ranges.

Contrary to popular belief, interior areas of Siberia, northern Canada, and Alaska have pleasantly warm summers with many hours of sunshine each day. Figure 168 shows the average number of days during each year that the temperature does not fall below freezing. Notice that interior areas have more warm days than do the coastal areas.

Characteristic temperatures of the Arctic during summer and winter are given below:

Interior Areas. During summer, temperatures in interior areas often climb to the mid 60's or low 70's, sometimes rise to the high 70's or 80's, and occasionally even into the 90's. Fort Yukon, Alaska, located just north of the Arctic Circle, has recorded a temperature of 100° F.; Verkhoyansk, in north central Siberia, has recorded 94° F.

During winter, temperatures are usually well below zero in the northern parts of the continental interior. During these long hours of darkness, temperatures normally fall to —20° or —30° F., and in some isolated areas, the daily minimum reading may drop to —40° F. The normal lowest daily temperature in north central Siberia in winter is between —45° and —55° F., and Verkhoyansk, located in this region, has the record for the Northern Hemisphere with a low of —94° F. Snag, in the Yukon Territory of Canada, holds the record for North America with a reading of —83° F.

Water and Coastal Areas. Arctic coastal areas, including the Canadian Archipelago, have relatively cool, short summers. Temperatures usually climb to the 40's or low 50's, and occasionally reach the 60's. There is almost no growing season along the coasts, and the temperature falls below freezing during all months of the year. The minimum temperature at Barrow, Alaska falls below freezing on all but about 42 days a year.

During winter, it is a rare occasion when the temperature climbs above freezing anywhere along the Arctic coast. Although very cold, this area is not nearly as cold as some interior areas of Canada and Siberia, where minimum daily temperatures average 20° F. colder. The North Pole is not as cold as some interior areas because of the flow of heat from the water under the ice.

Temperatures over the Arctic Ocean are similar to those along the coast, although summer temperatures are somewhat colder, rarely climbing above 35° F. This is not surprising since the ice pack covers most of the Arctic Ocean during the entire year.

CLOUDS AND PRECIPITATION

As mentioned earlier, cloudiness over the Arctic is at a minimum during the winter and at

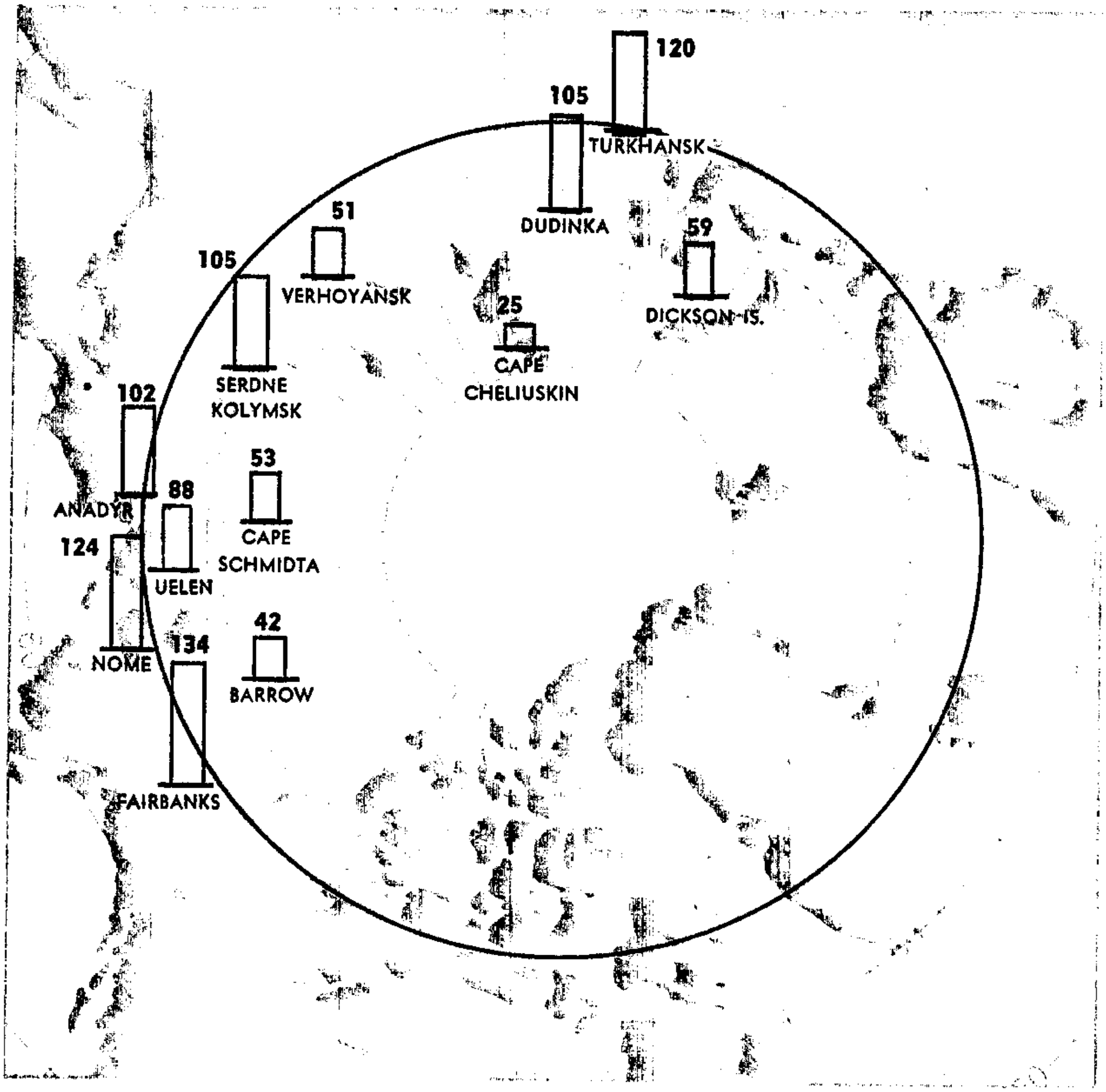


FIGURE 168. Average number of days each year with minimum temperatures above freezing.

a maximum in summer and fall, although there are many cloudy days in spring. The average number of cloudy days at selected locations for the cold and warm seasons is shown in figure 169.

Scattered cumulus clouds form over interior regions during warm summer afternoons. Occasionally they grow into thunderstorms, but the thunderstorms seldom form a continuous line. Along the Arctic coast and over the Arctic Ocean, thunderstorms occur very infrequently. Although tornadoes have been observed near the Arctic Circle, their occurrence is extremely rare.

Precipitation in the Arctic is generally light. Annual amounts over the ice pack and along the coastal area are only 3 to 7 inches. The interior is somewhat wetter, with annual amounts of 5 to 15 inches.

As the above annual precipitation amounts indicate, the climate over the Arctic Ocean and adjoining coastal areas is as dry as some of the desert regions of the United States. Any precipitation which does fall in these Arctic areas and on the icecaps is usually in the form of snow. On the other hand, interior areas get mostly rain.

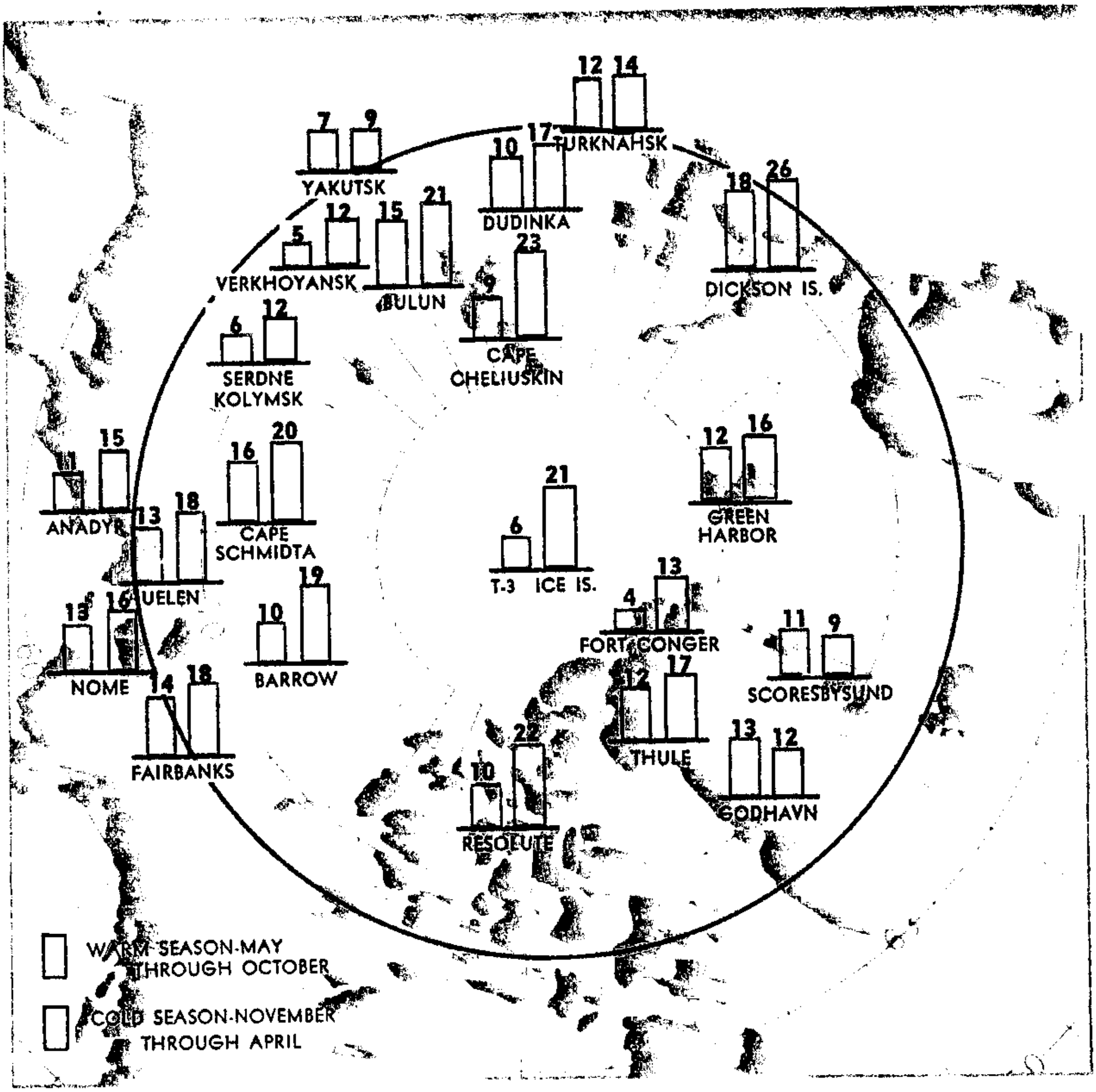


FIGURE 169. Average number of cloud days per month.

ICING

While most Arctic air masses exhibit a pronounced dryness in all but the lowest layers, moisture may find its way to considerable heights in maritime polar air masses. This in turn sets the stage for icing conditions, which the pilot should anticipate whenever ascending through thick cloud layers above open water areas. On occasion, icing may even be encountered when passing through what appears to be clouds of relatively thin consistency. While cloud masses along coastal areas are always suspect, clouds capable of producing icing may be carried far inland by strong onshore winds aloft. Most icing occurs in the form of rime (although a combination with clear ice is not unusual in coastal mountain areas) and, under certain conditions, may build up rapidly to dangerous proportions.

FROST

In coastal areas during spring, fall, and winter, heavy frost and rime may form on aircraft parked outside hangars. This is especially true if fog or ice fog is present. Heavy deposits of frost and rime may affect the airfoil and cause loss of lifting power—a situation that can be hazardous if the surrounding terrain demands a rapid rate of climb in order to clear mountain peaks.

WINDS

Strong winds occur more frequently along the coast than elsewhere in the Arctic, and with greater speed as well. Speeds greater than 70 knots have been recorded at a number of coastal stations. The frequency of occurrence of high winds in coastal areas is greatest in fall and winter. Along the coast of Greenland, winds in excess of 90 knots are not uncommon during the winter months.

Strong winds are infrequent over the ice pack. Winds were observed for a year at Fletcher's Island (T–3) near the North Pole, and speeds exceeded 28 knots on only one occasion. However, the wind blows steadily because there are no hills or mountains to hinder it. Winds, combined with low temperatures, make the Arctic coastal area and the area over the ice pack very uncomfortable, severely limiting outdoor human activity.

Wind speeds are generally light in the continental interior during the entire year, but are normally at their strongest during summer and fall. In winter, high pressure systems with light winds develop in these regions.

VISIBILITY

The "Whiteout" Hazard. Occasionally a "whiteout," an optical effect restricting visibility but unlike falling or blowing snow, fog or smoke, occurs in the Arctic (and Antarctic) region. The ingredients for a "whiteout" are snow or ice-covered surface terrain and a layer of cloudiness of uniform thickness covering most of the sky. The parallel rays from the sun are broken up and diffused when passing through the cloud layer so that they strike the snow surface from many angles. This diffused light is then reflected back to the cloud, and then to the surface of snow again—countless times until all shadows are destroyed. (The same effect can be duplicated in a white room with multiangle mirrors on the ceiling and floor.) Most "whiteouts" occur when the cloud deck is relatively low and the sun is at an angle of about 20° above the horizon. The result is a loss of depth perception. Buildings, people, and dark-colored objects appear to float in the air, and the horizon disappears. Passage over the snow becomes hazardous, especially in crevasse areas. Low-level flight over icecap terrain and landings on snow surfaces become dangerous. Several disastrous aircraft crashes have occurred in recent years in which a severe whiteout condition may have been a factor.

Fogs. Fog limits landing and takeoff operations in the Arctic more than any other visibility restriction.

ICE FOG

Ice fog is the major restriction to aircraft operations in winter because it occurs often and tends to persist. Rarely found outside Arctic climates, ice fog is composed of tiny ice crystals (rather than water droplets as found in ordinary fog). It forms in moist air during extremely cold, calm conditions. The tiny ice crystals often are called needles or spicules, and when the sun shines on these suspended particles, very bright reflections or shimmering lights result. Effective visibility is dependent largely upon whether one is looking toward or away from the sun.

Although ice fog may be produced both naturally and artificially, that which affects aviation operations most frequently is produced by the combustion of aircraft fuel in cold air. When the wind is very light and the temperature is about $-30°$ F. or lower, ice fog often forms almost instantaneously in the exhaust gases of automobiles and aircraft. It sometimes lasts for days, but its duration may be as little as a few minutes.

ADVECTION FOG

Advection fog, which may be composed either of water droplets or of ice crystals, occurs even more often than the ice fogs described above.

It is more common in winter and often is very persistent. Advection fog forms along coastal areas facing the wind flow; it usually lies in a belt parallel to the shore and forms as comparatively warm, moist air moves over cold land from water areas. If the land area is hilly or mountainous, lifting of the air often will result in low stratus clouds in combination with the fog. The stratus and fog quickly diminish inland. Lee sides of islands and mountains usually are free of advection fog because of mechanical turbulence and heating of the air by compression as it descends the slopes.

STEAM FOG

Steam fog, often called "sea smoke," forms in winter when cold, dry air passes from a land area over the comparatively warm ocean waters. Moisture evaporates rapidly from the water surface, but since the cold air can hold only a small amount of moisture, condensation takes place just above the surface of the water and appears as steam rising from the ocean. The fog is composed entirely of water droplets, which often freeze quickly and fall back into the water as ice particles.

Arctic Haze. Pilots in flight over the Arctic sometimes experience reduced visibility in the horizontal and in looking at surface objects at an angle other than from directly above. Color effects suggest that extremely small ice particles cause this condition. It is called "Arctic mist" or "frost smoke" when near the ground; when the sun shines on the ice particles, they are called "diamond dust."

Blowing and Drifting Snow. Blowing snow constitutes a greater hazard to flying operations in the Arctic than in midlatitudes because the snow is dry and fine and is easily picked up by the winds. Winds in excess of 8 to 12 knots may

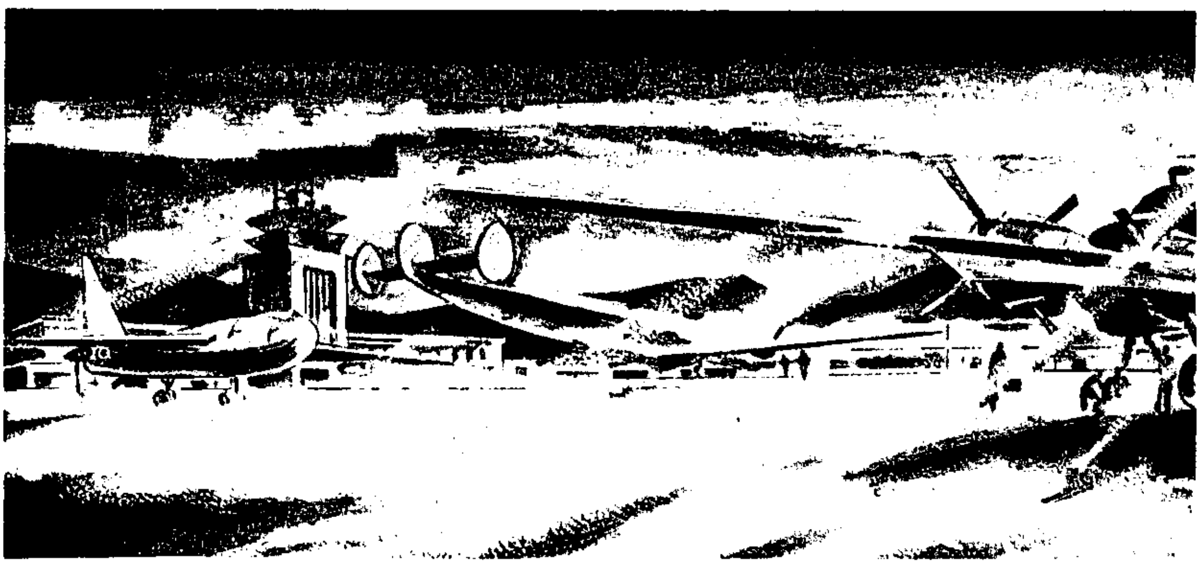


FIGURE 170. Visibility reduced by blowing snow.

raise the snow several feet off the ground, causing objects (such as runway markers) to become obscured (illustrated in fig. 170). Under certain conditions, a sudden increase in surface winds may cause unlimited visibility to drop to near zero within a few minutes time. This occurs frequently and without warning in the Arctic.

Stronger winds sometimes lift blowing snow to heights above 1,000 feet and produce drifts over 30 feet deep. Although surface drifting of snow may occur without restricting vertical visibility, the drifts may still obstruct horizontal visibility during takeoff and landing.

Smoke. Another possible hazard, smoke, is serious in the Arctic only in the vicinity of larger towns, often occurring in winter with shallow radiation fogs.

ARCTIC WEATHER PECULIARITIES

EFFECTS OF TEMPERATURE INVERSIONS

The rapid increase in temperature with height at low levels over the Arctic during much of the winter causes several interesting phenomena. Sound tends to carry great distances under these inversions. When the inversion is very strong, people's voices may be heard over extremely long distances as compared to the normal range of the human voice. Light rays are bent as they pass through the inversion at low angles. This may cause the appearance above the horizon of objects that are normally beyond the horizon. This effect, known as "looming," is a form of mirage. Mirages which distort the apparent shape of the sun, moon, and other objects are common with these inversions.

AURORA BOREALIS

More commonly known as the Northern Lights, the Aurora Borealis has its counterpart in the Antarctic, where it is termed the Aurora Australis or Southern Lights. While the Northern Lights occur in the Arctic region, they take place at high altitudes above the earth's surface (rays have been measured up to 600 miles above the earth), and thus have been observed as far south as Florida. However, the highest frequency of observations is at latitudes of the northern United States and farther north. Displays of aurora vary from a faint glow to an illumination of the earth's surface equal to that of a full moon. They frequently change shape and form, appearing as rays, arcs, rayed arcs, and draperies. During very active occurrences, they may be accompanied by pulsating surfaces that flash rapidly from horizon to zenith. The most predominant color is pale green, but yellow, white, red, blue, and violet sometimes are observed.

Investigation has shown a relationship between sun spot activity and the aurora. In theory, energy particles from the sun strike the earth's magnetic field and are carried along the lines of force, where they tend to lower and converge near the geomagnetic poles. In these regions, they pass through rarefied gases of our outer atmosphere, illuminating them in much the same way as electrical charges illuminate neon gas in our neon signs.

LIGHT REFLECTION BY SNOW-COVERED SURFACES

Much more light is reflected by snow-covered surfaces than by the darker surfaces found at middle and low latitudes. The Arctic, therefore, is illuminated more by a source of light than areas to the south would be by light of equal intensity. When the sun is shining, sufficient light often is reflected from the snow surface to nearly blot out shadows. This markedly decreases the contrast between objects, and it becomes very difficult to distinguish between them. The landscape may merge into a featureless grayish-white field. Dark mountains in the distance may be easily recognized, but a crevasse (rift in a glacier or mass of land ice) normally directly in view may be undetected due to lack of contrast.

LIGHT FROM CELESTIAL BODIES

Pilots have found that light from a half-moon over a snow-covered field may be sufficient for landing purposes in the Arctic. On some occasions, one can read a newspaper with the illumination from a full moon. Even illumination from the stars creates visibility far beyond that found elsewhere. Only during periods of heavy overcast skies does the night darkness in the Arctic begin to approach the degree of darkness in lower latitudes. There are often long periods of moonlight, with the moon staying above the horizon for several days at a time.

ARCTIC WEATHER AND AVIATION OPERATIONS

For the most part, fewer and less-severe weather hazards exist in the Arctic for aircraft at *flight altitudes* than in other regions. But areas on Greenland compete with the Aleutians for the world's worst weather. These places are exceptions, and flying conditions in the Arctic are good when averaged over the entire year.

During takeoff and landing in the Arctic pilots often encounter troublesome low ceilings and visibilities as well as an even greater hazard—the loss of depth perception as a result of "white-outs."

ARCTIC FLYING WEATHER IN SUMMARY

Ice fog is the major restriction to aircraft operations in winter. While no more hazardous than ordinary fog except that it sometimes restricts visibility even more, it constitutes a serious problem because of its frequency and persistency. Ordinary water-droplet fogs also present problems and can cause aircraft icing as well as restrict visibility. In addition, blowing and drifting snow often cause poor visibility at terminals.

Winter is characterized by frequent storms and well-defined frontal passages; however, because of the dryness of the air, cloudiness and precipitation are at a minimum. Turbulence is likely to be encountered, especially in mountainous areas. In-flight weather otherwise is generally good. Aircraft icing sometimes is encountered in winter, but it is more likely in spring and fall when operational flying conditions are usually worse. Icing during these transitional periods between winter and summer may extend to high levels, while frontal zones are usually active and turbulent.

Over the Arctic Ocean and along the coastal areas, blowing snow and strong surface winds are the main hazards during autumn and winter. Blowing snow may be deceptive to the inexperienced pilot, since the shallowness of the snow layer usually permits good vertical visibility at the same time that the horizontal visibility within the layer is very poor. Fog is the main hazard to aircraft operations in these coastal areas during summer, occurring on an average of 19 days each month in June, July, and August. Fog is a potential source of aircraft icing when the temperature is between freezing and $-10°$ F. ($-23°$ C.).

Over the continental interior, good flying weather prevails most of the year. In terms of ceiling and visibility, the summer months provide the best flying weather. However, the number of cloudy days during the summer exceeds those in winter. Cloudiness and precipitation are more widespread than in winter because the higher temperatures can support more moisture in the air. Low pressure systems and fronts are fewer and weaker in summer, and very seldom cause severe turbulence, icing, or strong winds. Thunderstorms do develop on occasion during the summer, but they usually can be circumnavigated without much interference with flight plans.

Takeoffs should not be attempted when frost, ice, or snow is on the aircraft wings. Even a thin layer of snow may not blow off—and only a thin layer may contribute to a serious crash. Hoarfrost often forms on the wings when aircraft are left outside in extreme cold. This should always be removed before operating the aircraft.

Operation of jet aircraft in the Arctic is simpler in at least two respects than the operation of conventional aircraft. Jet aircraft do not require a warmup period after being exposed to the cold temperatures. Neither jet nor conventional aircraft require as long a runway for takeoff in the Arctic as they need in temperate climates because of the greater density of cold air. Jet aircraft are affected more by differences in air density than are conventional aircraft.

ADDITIONAL INFORMATION ON ALASKAN FLYING WEATHER

As most of Alaska's air routes cross mountain passes, pilots must take several precautions. Because weather conditions in a mountain pass usually are poorer than at reporting stations on either side of it, sufficient airspace to permit a 180° turn short of reaching a pass is essential to flying safety. Winds blowing through the passes are especially strong when pressure systems are intense, a frequent situation in Alaska in winter. Turbulence, not obvious from the reports of nearby weather stations, may be severe. Pilots should make every effort to obtain a preflight briefing. Knowledge of pressure gradients (ch. 4) gives a pilot a good idea of wind conditions and turbulence he would be likely to encounter in the passes. Additionally, winds aloft information gives the probability of mountain waves (ch. 7).

Pilot reports are especially valuable to those persons contemplating flights in Alaska, not only because of the rugged terrain, but also because weather stations, for the most part, are quite far apart. Enroute weather often is radically different from that observed at official weather reporting stations. When receiving his preflight briefing, the pilot should ask about the unfamiliar places on his route.

With the dominance of snow cover in Alaska during winter, "whiteouts," in conjunction with overcast skies, often present a serious hazard, especially for pilots who are not prepared to fly under Instrument Flight Rules. When these conditions exist, no attempt should be made to cross mountain ranges under Visual Flight Rules (VFR). Many of the mountain peaks in Alaska are treeless and rounded rather than jagged, making them unusually difficult to distinguish under poor visibility conditions.

Another significant hazard to mountain-pass flying in Alaska is the prevalence of "false passes." These "false passes" are dead ends which often look better than the actual passes. Frequently there is insufficient room to make a 180° turn in a dead-end pass, and the usual result is disastrous.

ALTIMETRY

Large altimeter errors, caused by strong low pressure systems and much-below standard temperatures, are common in the Arctic. If pilots in the Arctic understand these errors and their causes, the hazards they represent can be eliminated almost completely. By consulting the weather forecaster, pilots can plan flights to compensate for anticipated altitude errors, which may be as much as 2,000 feet or more. Such dangerous errors are relatively common, except in summer.

The requirement for oxygen is determined by the atmospheric pressure at which the aircraft is flying. Pressure altitude, corrected for the mean temperature of the layer of air between the aircraft and the ground, should be used as the oxygen-demand altitude. The pilot should remember this when an increase in pressure altitude is required to clear known obstacles on the proposed route of his aircraft. Additional information on pressure altimeters is given in chapter 3.

SOME COMMENTS ON EMERGENCY LANDINGS IN THE ARCTIC

Emergency landings on Arctic sea ice are dangerous because of the unevenness of ice and snow surfaces. This is especially true of old ice, where winds, tides, and currents have caused ridges (called pressure ridging) and piles (called hummocks) of ice. In summer, vast areas of ice are broken up into floes with cracks and open leads running through them. New ice formed in the fall, called "black ice," appears from the air like a dark blotter under a sheet of glass. An early snowfall may hide this feature and tempt an inexperienced pilot to land on it—possibly with dire results since the ice may be too thin to support the weight of his aircraft.

Recognition of "ice blink" and "water sky" may aid a pilot who faces an emergency landing. Ice blink is a relatively bright, usually yellowish-white glare on the underside of a cloud layer. It is produced by light reflected from an ice-covered surface, such as pack ice. Brightness of the glare on cloud bases varies, and the pattern of brightness is called the "sky map." Ice blink is not as bright as "snow blink" (glare produced by light reflection from a snow surface), but it is much brighter than "water sky" or "land sky." Water sky is the comparatively dark appearance of the underside of a cloud layer over a surface of open water, as viewed when flying over ice and snow. (A pilot unfamiliar with water sky may think it indicates extremely bad weather.) The ability to recognize water sky can be of obvious help to a pilot who has to make an emergency landing.

Chapter 21
TROPICAL WEATHER

The Tropics, technically speaking, include that vast region of the Earth which lies between the Tropic of Cancer (23½° N. latitude) and the Tropic of Capricorn (23½° S. latitude). However, atmospheric conditions characteristic of tropical weather on occasions occur more than 45° of latitude from the Equator. This is especially true for the east coasts of continents.

The atmospheric pressure field is predominantly low in the Tropics, and pressure gradients are ordinarily weak except in tropical cyclones. Since there are no well-defined pressure systems in this region other than in these cyclones, local pressure variations frequently are due only to the diurnal effect. The diurnal pressure variation in the Tropics sometimes exceeds 5 millibars (0.15 inch of mercury). However, the main difference between tropical weather and the predominant weather of middle and high latitudes is the relative absence of fronts. Only on rare occasions are fronts strong enough to move into the Tropics, and these occasions obviously are in winter. Fronts reaching the Tropics are accompanied by thunderstorms only if conditions aloft are also favorable (such as the presence of an upper low). Almost all fronts which reach the Tropics produce rain showers, some shift of wind, and a small reduction in temperature.

Most weather in the Tropics occurs as a result of changes within an air mass. The typical day-to-day weather which occurs over the tropical oceans differs from weather over tropical continental areas. Along coastal regions and over islands, a combination of these two types (land and ocean) usually results. Typical weather patterns are discussed first, followed by a treatment of the changes in weather caused by longitudinally moving systems and the migrating equatorial trough.

OCEANIC TROPICAL WEATHER

In typical weather over the tropical oceans outside the equatorial trough, about one-half of the sky is covered with clouds. The bases of the clouds are commonly at about 2,000 feet, but they occasionally lower to 1,500 or 1,000 feet in scattered rain showers. The heights of cloud tops vary greatly, depending primarily upon the area where the clouds form. Tops in the trade wind belt vary from about 3,000 to 10,000 feet, according to the height of the persistent temperature inversion. The trade wind inversion tends to be lowest in the southeast quadrant of subtropical highs, gradually becoming higher toward the southwest quadrant, where it often disappears. Scattered rain showers frequently fall from these cumulus clouds, which tend to form in bands paralleling the wind flow. Visibility is good, except in the rain showers.

Dew points stay almost constant in the oceanic Tropics. The relative humidity, therefore, is controlled by the temperature—the higher the temperature, the lower the relative humidity. But even the temperature variation is small over the tropical oceans, rarely varying more than 4° F. from day to day or from month to month. The freezing level is usually between 15,000 and 16,000 feet throughout the year.

Wind is the most important causative factor in tropical weather, both over land and oceanic areas. When there is convergence of wind flow, air piles up locally and results in vertical motion. Chapter 11 indicated that convergence is one of the types of lifting actions which can produce thunderstorms. Even if not sufficiently strong to produce thunderstorms, convergence in the Tropics almost always results in towering cumulus clouds and heavy rain showers.

Convergence in the wind flow can occur with little change in the pressure pattern at the surface. The Coriolis force is less in the Tropics than at higher latitudes and becomes zero at the Equator. It is, therefore, too weak in the Tropics to balance the pressure gradient force, and winds may blow at large angles across isobars.

CONTINENTAL TROPICAL WEATHER

The weather over interior continental areas within the Tropics is subject to extreme climatic variation. Factors which control the climate are (1) the pressure pattern and wind flow; (2) orientation, height, and extent of coastal mountain ranges; (3) altitude of the continental area; and (4) rate of evaporation from the surrounding ocean surface. Various combinations of these factors produce tropical weather ranging from the hot, humid climate of the lower Congo River, to the arid Libyan Desert, and to the snowcapped mountains of Kenya and South America. Snow is not uncommon on the higher mountain peaks of the Hawaiian Islands. The two *major* climatic groups of the tropical continental areas are the arid (or semiarid) climates, and the humid (jungle or rain forest) climates.

ARID TROPICAL WEATHER

The climate of land areas to the lee of mountain ranges or on high plateaus is characterized by hot, dry, unstable continental air (for example, the desert regions of South America and Africa). The afternoon temperature may be in excess of 100° F. in these areas, but the night temperature in desert regions may drop below freezing. Strong convection is present during the day, but the relative humidity is so low at the surface that the cumuliform cloud bases are above 10,000 feet. Precipitation falling from high-based thunderstorm clouds often evaporates completely before reaching the ground. The "dry" thunderstorms, however, produce squall winds and may cause severe duststorms or sandstorms. Severe turbulence aloft and restricted ceiling and visibility, accompanied by gusts and squalls near the ground, present hazards to aircraft. Blowing sand may cause extensive damage to inadequately protected aircraft on the ground.

HUMID TROPICAL WEATHER

Where no mountains or high terrain are present to obstruct the flow of maritime air onshore, the warm moist air influences wide continental areas of the Tropics. Cloudiness and precipitation are at a maximum over these jungle regions and tropical rain forests.

In humid tropical climates, the daily variation of wind direction and speed determines the daily variations in cloudiness, temperature, and precipitation. Slight shifts in the wind direction may cause the air to condense much of its moisture over hills, or to come from a different marine source region with less moisture. Slight increases in wind speed may reduce the effect of radiational heating of the ground and result in fewer convective currents and clouds. Clouds are predominantly cumuliform with afternoon cumulonimbus, but thick early morning steam fog often forms in the jungles. The average daytime cloud coverage is approximately 60 percent of the sky throughout the year, with maximum cloud coverage during the day. The high moisture content and extensive cloud coverage reduce summer heating and winter cooling.

The annual range in temperatures for jungle stations may be less than 2° F., but the daily range is often 30° F. or more. When afternoon showers occur, the descending cold air currents may produce nights with temperatures in the 60° F. range. These rain showers are very heavy and produce low clouds that may reduce ceiling and visibility to near zero.

ISLAND AND COASTAL TROPICAL WEATHER

Weather conditions are similar along coastal areas and over the various mountainous islands of the Tropics. During the day as warm, moist air moves inland and is lifted over the terrain, large cumuliform clouds develop. While these clouds are common in coastal areas, the lifting of moist air on the windward side of mountainous islands also produces towering cumulus clouds. These clouds frequently may be seen from long distances, indicating the presence of an island ahead. Cumuliform clouds and precipitation are more abundant over coastal areas and islands (even low ones) than over the open oceans, except in the vicinity of the tropical weather disturbances discussed below.

INTERTROPICAL CONVERGENCE ZONE

The northeast trade wind belt of the Northern Hemisphere and the southeast trade winds of the Southern Hemisphere are separated by a broad area of relatively low pressure and light winds. This area of lower pressure is, in the mean, near the Equator and, as a result, is often referred to as the "equatorial trough." The light wind associated with it has led to the names "doldrum belt" or "belt of calms." Due to the general light wind flow, land and sea breezes become the predominant wind for extended periods along coastal areas and near islands in this belt. The equatorial trough migrates northward from the general area of the Equator in the Northern Hemisphere's summer season, and southward in the Southern Hemisphere's summer, moving with the zone of greatest solar radiation.

Convergence of the northeast and southeast winds is always present to a degree, and usually some amount of unsettled convective weather is found in the trough at all times. When this zone of convergence intensifies, thunderstorms develop and sometimes produce wind gusts of 40

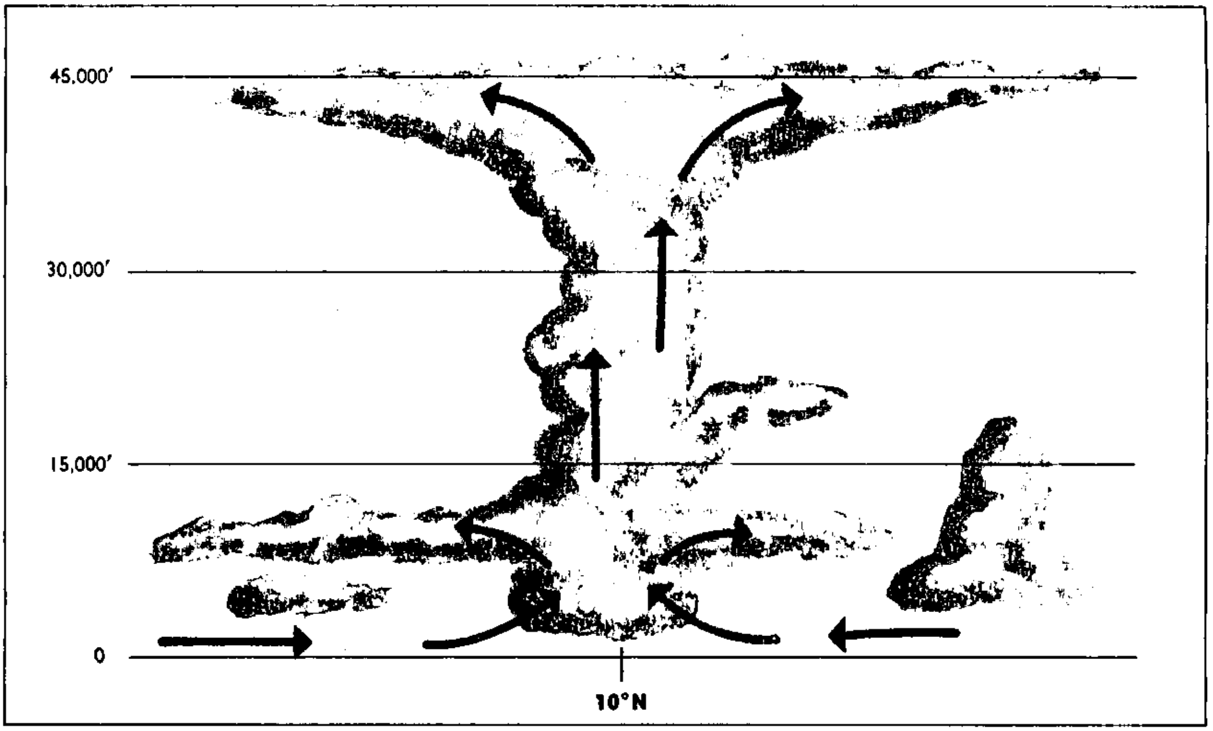


FIGURE 171. Vertical cross section of the Intertropical Convergence Zone.

to 60 knots. These blasts of wind in the "belt of calms" sometimes catch the uninitiated by surprise. The severity of convective activity may vary considerably from longitude to longitude within this zone, called the "Intertropical Convergence Zone."

The Intertropical Convergence Zone is usually at its broadest and weakest when it is centered near the Equator. This position is dominant in the respective hemisphere's spring and fall. When the trough is displaced considerably from the Equator (in the respective hemisphere's summer), the convergence tends to increase, and the zone tends to become narrower. It has the appearance of a front because the rising, warm, moist air produces a line of cumulonimbus clouds and thunderstorms. Cloud tops usually extend above 40,000 feet, and tops above 60,000 feet are not uncommon. Extensive sheets of cirrus usually spread north and south of the cumulonimbus clouds. However, the Intertropical Convergence Zone is not a true front because there is no significant discontinuity in air densities. Figure 171 illustrates the vertical structure of this convergence zone.

Sometimes the Intertropical Convergence Zone is split into two lines of convective activity, one to the north and the other to the south of the Equator. This is most apt to occur when the northeast trades of the Northern Hemisphere and the southeast trades of the Southern Hemisphere are separated by an unusually broad area of light winds. The convergence of wind flow is found along the line in each hemisphere where the light winds border on the stronger trade wind belts.

EASTERLY WAVES

The "easterly wave" is a common tropical weather disturbance, normally occurring in the trade wind belt. Easterly waves occurring in the Northern Hemisphere have advance winds somewhat more northerly (NE or NNE) than the usual trade wind direction. As the wave line

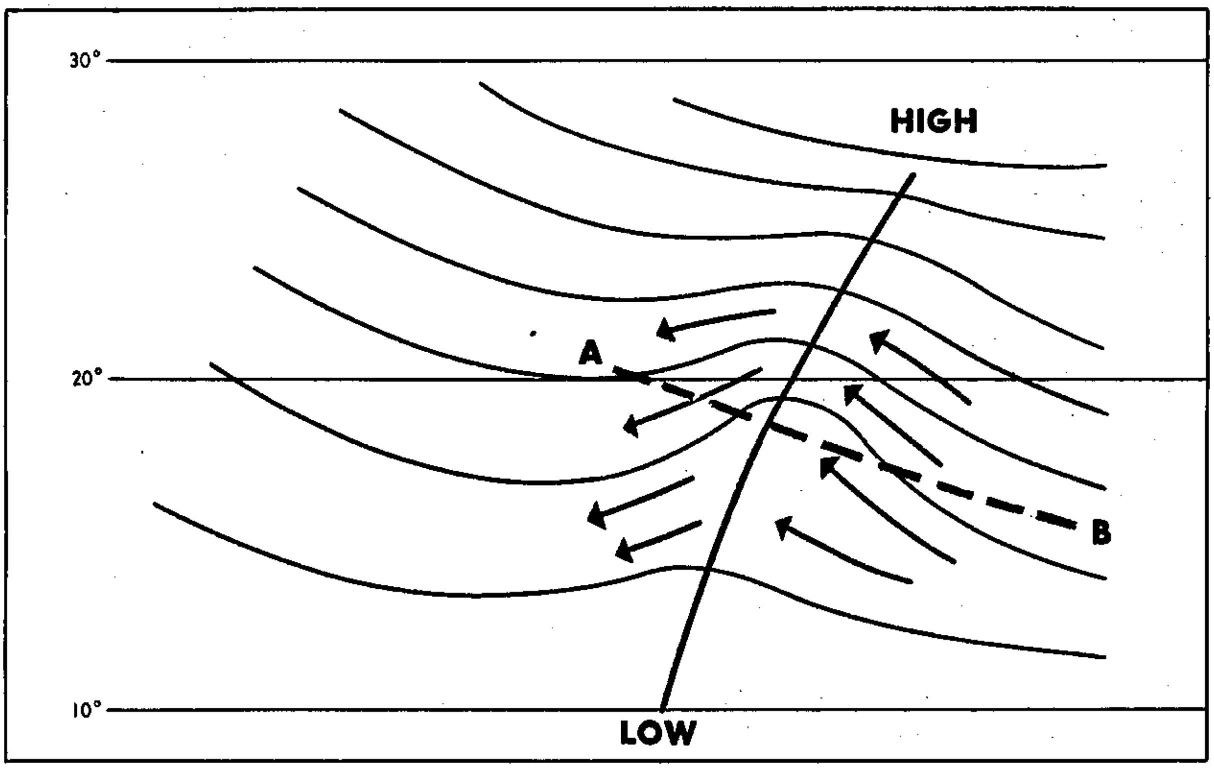


FIGURE 172. A Northern Hemispheric easterly wave on a surface weather chart.

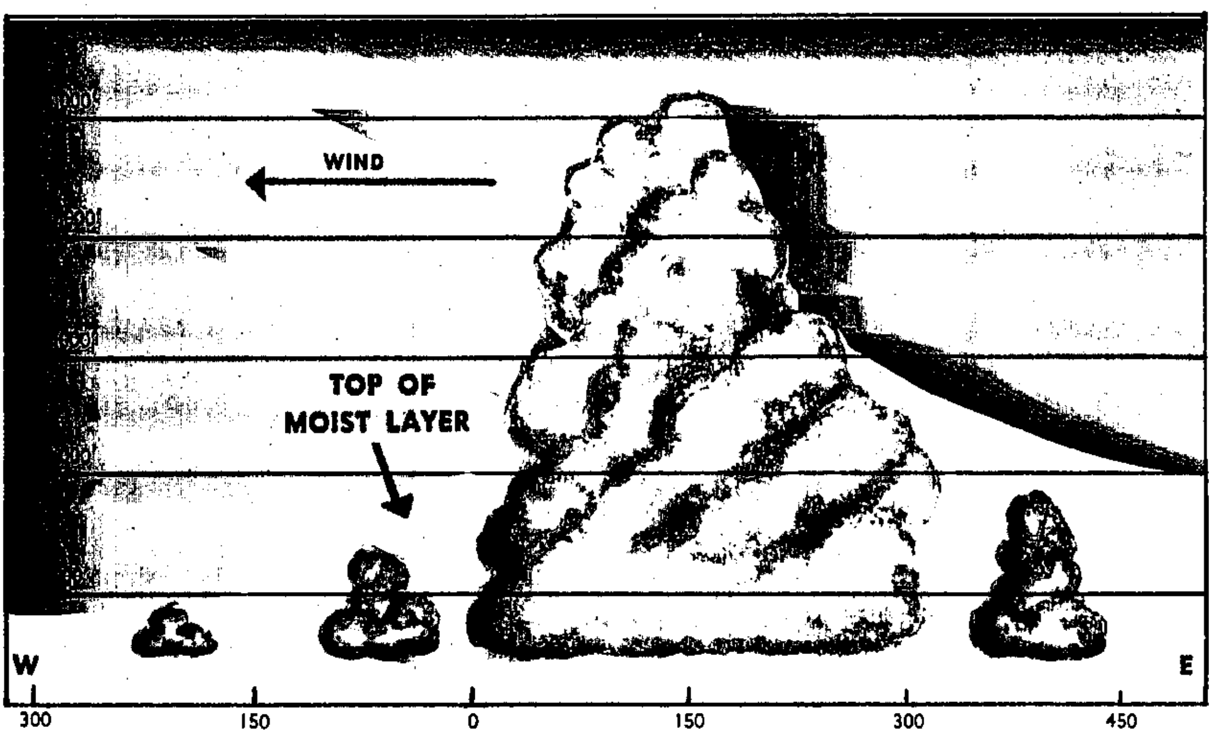


FIGURE 173. Vertical cross section along line A -- B in fig. 172. (Abscissa in miles.)

approaches, there is a fall in pressure (fig. 172). The wind shifts to the east as the line passes, and then to the east-southeast or southeast. The typical wave is preceded by very good weather, but followed by extensive cloudiness, low ceilings, rain, and usually thunderstorms. The weather activity is found in roughly a north-south line. Other than having a different orientation, it resembles the frontal weather of the middle latitudes.

Easterly waves in the Northern Hemisphere usually develop in the southeastern perimeter of subtropical high pressure systems and travel from east to west around the southern periphery of these highs with the prevailing easterly circulation of the Tropics. The waves usually move at a slower speed than the normal wind flow.

Easterly waves are common in all seasons, but are more numerous and stronger during summer and early fall. Their effects occasionally reach as far north as the Gulf Coast area in the United States. They frequently affect Hawaii and are commonly observed in the Greater Antilles and Lesser Antilles of the western Atlantic Ocean. Figure 173 shows the distribution of cloudiness in a typical well-developed easterly wave.

A wave which is hardly discernible on the weather chart one day may deepen rapidly and, by the next day, become the spawning ground of a tropical cyclone. Discussion of tropical cyclones is reserved for the last section of this chapter; less dramatic but far more common tropical weather patterns will be examined first.

SHEAR LINES

A line of wind shear, called simply a "shear line," often is found in the Tropics as the trailing end of a strong polar front which has moved unusually far to the south. This wind shear line develops when the leading edge of the polar air mass in its southward movement displaces the semipermanent subtropical high pressure system. Mixing in the southern latitudes causes density discontinuities across the front to disappear, leaving only a wind shift and a change of wind speed across the diffuse front. Convergence and cumuliform activity still may be found along this line of wind discontinuity, especially when it crosses high terrain. As the high pressure area behind the shear line advances, the subtropical high area ahead of the shear line tends to weaken, and the two highs gradually merge. The narrow band of activity is then replaced by a freshening of the trade winds.

Movement of polar fronts into the Tropics sometimes causes the subtropical high to split into two cells, inducing a trough between the cells. More than usual cloudiness and shower activity will be found in this trough, which may or may not show further development, depending on other atmospheric conditions. Figure 174 illustrates a shear line and an induced trough as they might appear on the surface weather chart.

THE POLAR TROUGH ALOFT

At altitudes of about 10,000 feet and above, polar troughs frequently extend well into the Tropics (fig. 175). These troughs often move southeastward and eastward through the Tropics with no noticeable effect on the surface pressure pattern. Extensive middle and high cloudiness usually is found east of the trough line.

At times, the trough aloft is very deep, and a closed low circulation develops in its southwestern extremity. The closed low aloft often breaks off from the trough and moves westward, producing an abnormally large amount of cloudiness and precipitation. It sometimes induces an easterly wave in the trade winds at low levels.

Polar troughs and lows aloft have a considerable effect on the amount of rainfall in the Tropics, especially over land areas where moun-

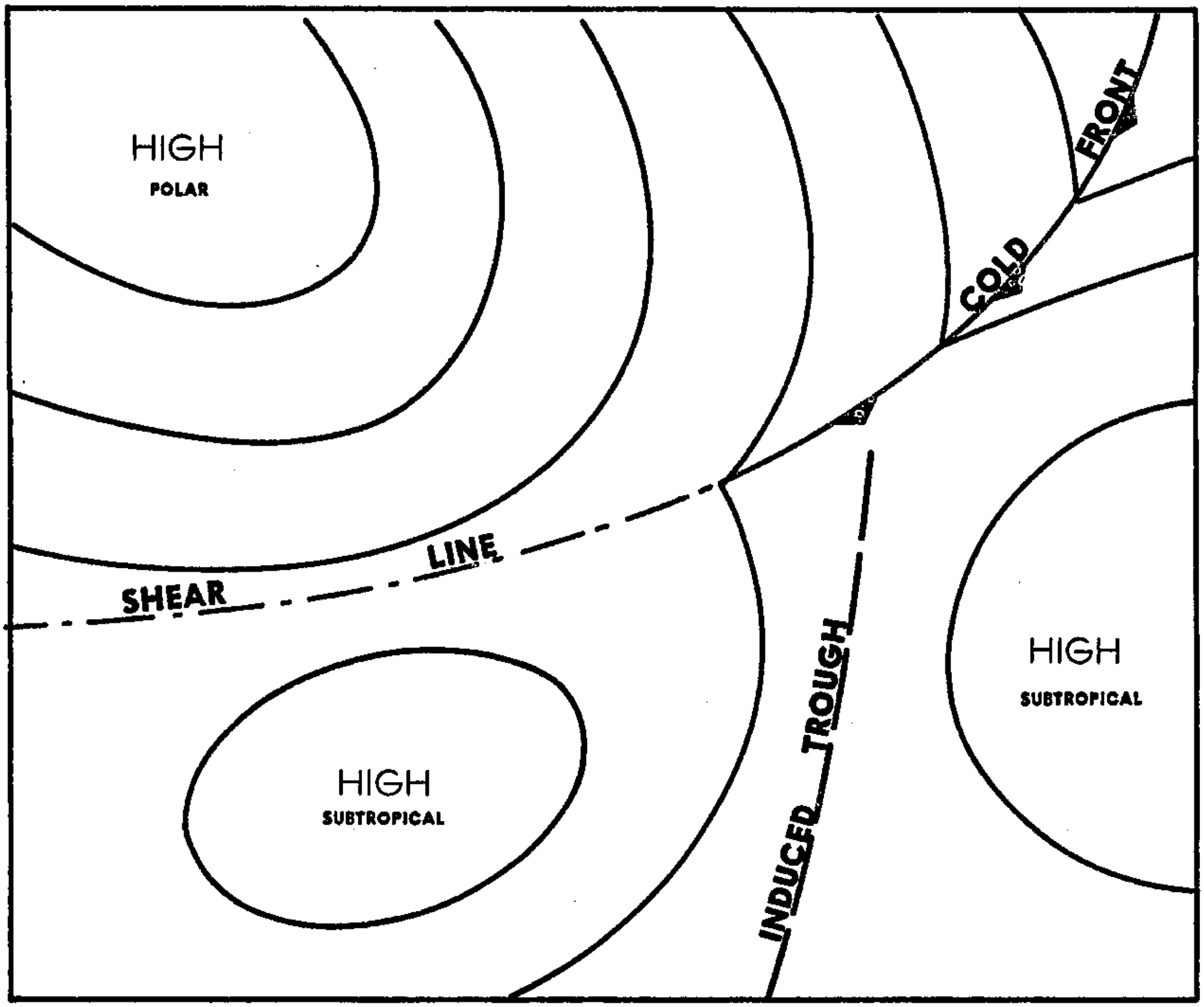


FIGURE 174. A shear line and an induced trough.

tains lift air to saturation. These low pressure areas aloft contribute significantly to the 460 inches of rainfall Mt. Waileale on Kauai in Hawaii receives as an annual average. Other mountainous areas of the Tropics are also among the wettest spots on earth.

MONSOONS

The "monsoon" is by definition a large-scale land and sea breeze which reverses its direction twice a year. Monsoons occur over a number of world areas, but the degree of influence on climatic conditions varies greatly. Southern and southeastern Asia are the continental areas most affected by this seasonal land and sea breeze. During the winter season, because of the large Siberian high, polar air flows southward across the Himalayan Mountain range toward the Equator (although the mountains interfere significantly with the flow and keep the coldest air from reaching India). This air is relatively dry and is warmed adiabatically as it flows down the southern slopes of the mountains. This is the dry or winter monsoon.

During the summer season, air from an equatorial source flows up over the mountains from

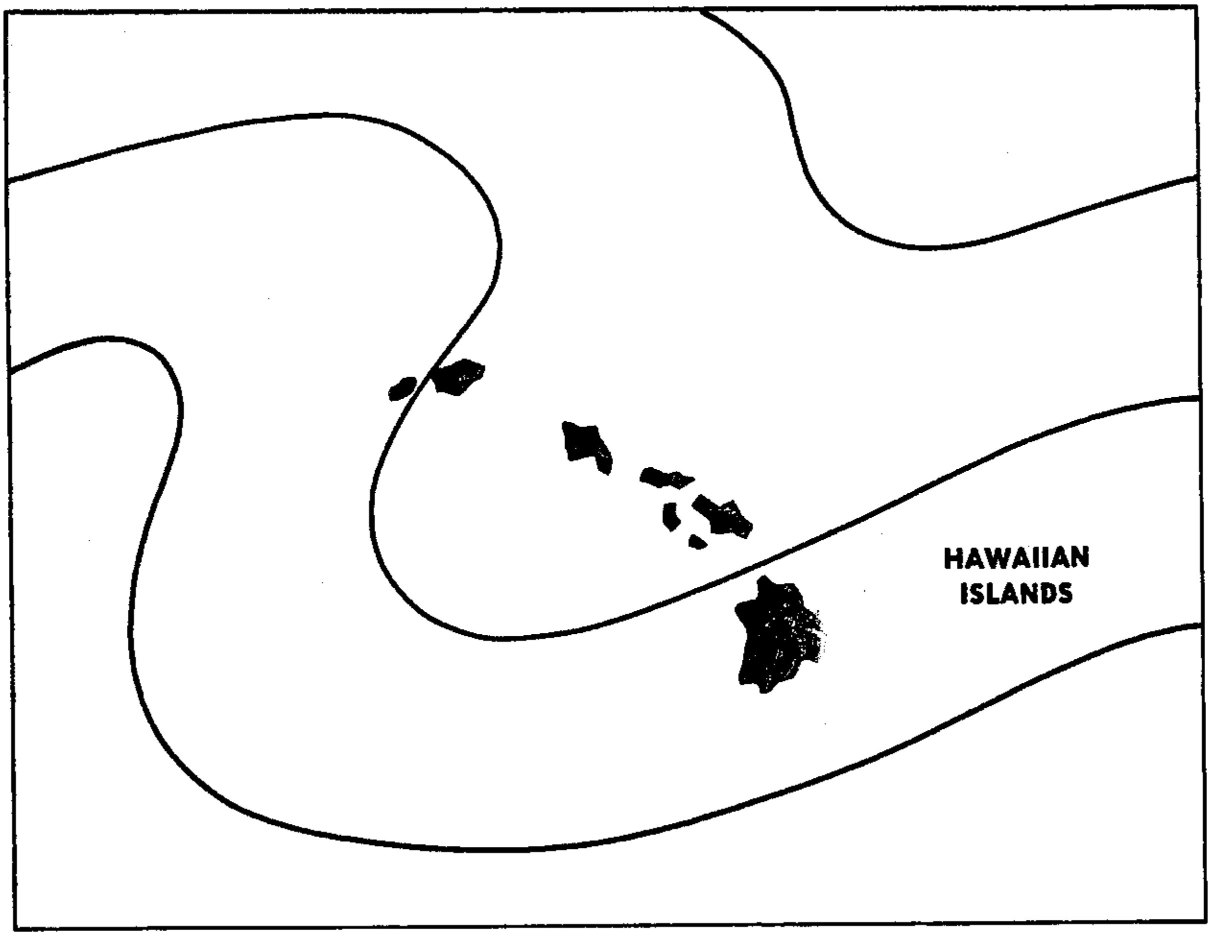


FIGURE 175. A polar trough aloft.

the south. The lifting of moist air in this area produces extensive cloudiness and widespread rain. The summer monsoon is responsible for some of the heaviest rains on earth. Stations in India report more than 400 inches of rainfall in a year, with most falling between the months of June and October.

TROPICAL CYCLONES

Many regional names are given to strong tropical cyclones (lows). Most Americans know them as "hurricanes," and this name is used for strong tropical cyclones in the Atlantic and Pacific Oceans, except in the western Pacific, where they are called "typhoons." Near Australia, strong tropical lows are called "willy willy's"; and in the Indian Ocean, "cyclones." In the terminology of the American meteorologist, a tropical cyclone is any "closed" surface low pressure system originating in the Tropics. "Closed" means that the pressure at the center of the system in the horizontal plane is lower than at any other point in the system.

BIRTHPLACES

Tropical cyclones which affect the United States originate over the warm (usually above 80° F.) tropical waters of the Atlantic Ocean, the Caribbean Sea, the Gulf of Mexico, the coasts of Central America and Mexico, and the eastern North Pacific Ocean. Figure 176 indicates the principal regions of the world where tropical

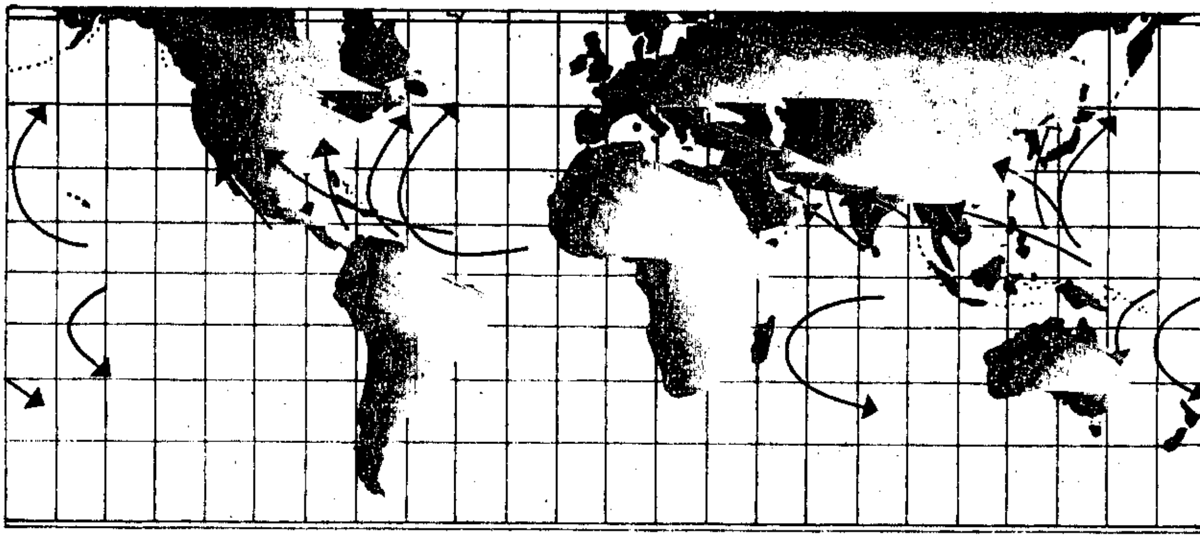


FIGURE 176. Principal regions where tropical cyclones form and their favored directions of movement.

cyclones form and their favored direction of movement. Note that most of them are born between 5° and 15° latitude.

DEVELOPMENT

Many tropical cyclones develop in easterly waves. They derive their energy largely from the heat given off by condensation of some of the great amount of moisture in the tropical air (ch. 5). Considerable heat is gained in the condensation process—enough to lower the atmospheric pressure and start a gradual inflow of air into the heated area. This flow would be directly toward the developing low center were it not for the Coriolis force (ch. 4), which deflects it to the right in the Northern Hemisphere. A cyclonic system with counterclockwise and slightly inward wind movement results. At this point in the cyclone's development (the formative stage), it is called a "tropical depression." Wind speeds associated with the depression are by definition 34 knots or less. By far the majority of tropical cyclones never grow beyond a "depression." But, on occasions, they grow to become "tropical storms," and even less often they become hurricanes (typhoons). The tropical cyclone is classified as a tropical storm when accompanying winds have speeds between 35 and 64 knots. In the mature stage, the cyclone reaches hurricane intensity and is characterized by winds of 64 knots or stronger. At this point, it might be well to mention that winds of 64 knots or more are referred to as *hurricane-force* winds, regardless of the type storm with which they are associated; but the term "hurricane" is properly applied only to tropical cyclones with winds of this strength. Winds associated with hurricanes are frequently in excess of 100 knots and have been recorded as high as 175 knots.

Some hurricanes grow from tropical depressions within 24 hours; others reach hurricane intensity only after several days.

The season of North Atlantic tropical storms and hurricanes is August, September, and October. They are very rare from December until May.

MOVEMENT

Tropical cyclones which do not grow to hurricane intensity usually move westward in the prevailing easterly flow of the Tropics until some external atmospheric influence destroys them. Hurricanes can be compared to spinning tops. Air masses involved with the low pressure system are spinning rapidly, and the movement of the low pressure system itself is sometimes very erratic.

The progressive movement of hurricanes while in the Tropics averages only 10 to 12 knots. Direction of movement in the Northern Hemisphere is usually westward or northwest-

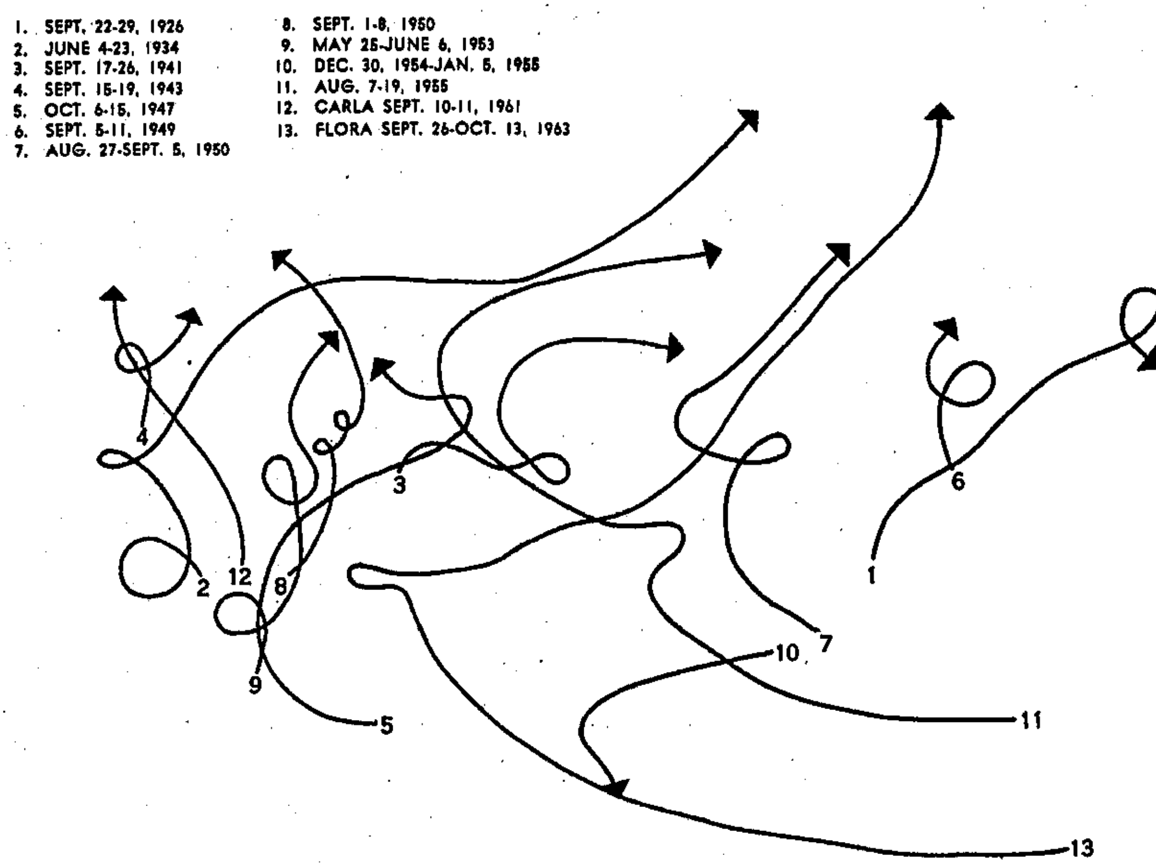


FIGURE 177. Tracks of some erratically moving tropical cyclones.

ward until they reach 25° to 30° N. latitude. At roughly this point, they often begin to recurve and thereafter move in a north to east direction. During recurvature, some hurricanes remain almost stationary for a day or more. Following recurvature, they usually move with rapidly increasing speed, sometimes faster than 50 knots. The generally accepted explanation of these movements is that hurricanes are steered by the general broadscale wind flow in which they are embedded. Their movement is influenced sometimes by two major wind currents, the trade winds at lower levels and the prevailing westerlies at higher levels. Variability of these influences may result in a number of loops, abrupt turns, and other erratic movements (see fig. 177).

EYE

Each tropical storm or hurricane has a relatively clear area in the center called the "eye" (see fig. 178). The sky in the storm center often is so clear that the sun or stars become visible, and the wind is comparatively calm. The temperature usually is higher and the air less moist than in the surrounding area. Around this "eye" is an encircling wall of violent hurricane-force winds, which produce a rumbling or roaring sound. Calm centers average 15 to 20 miles across, but some are less than 7 miles. The calm center is rarely wider than 30 miles. Birds frequently get caught in the "eye" as it moves away from a land area and cannot escape.

When the "eye" passes over any location, this calm center is preceded by winds of great violence from one direction and is followed by violent winds from the opposite direction. The return of violent winds after the calm causes some people to believe that the "storm came back." Many persons have died or have been injured because they did not know about the calm center in tropical storms and hurricanes.

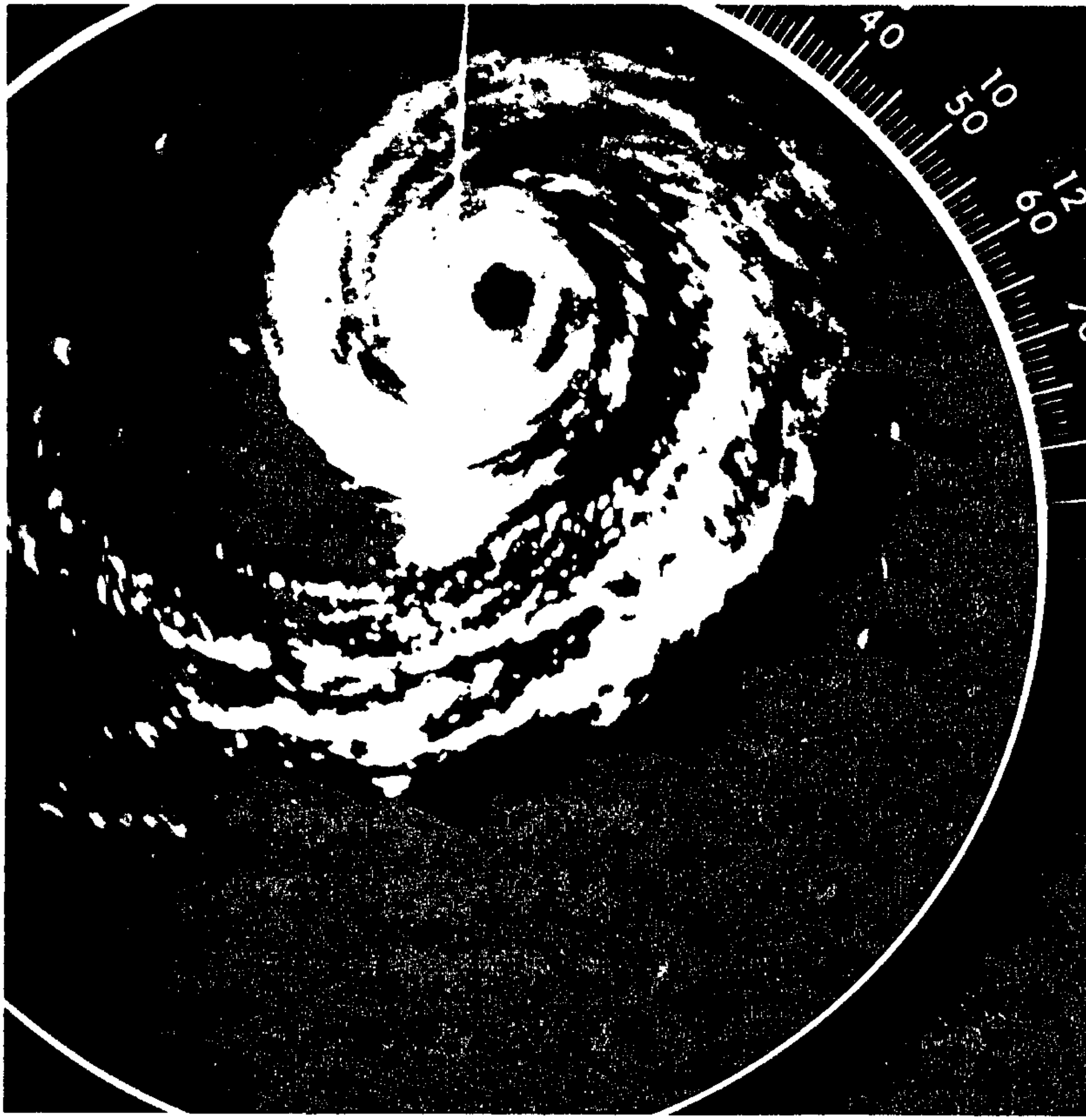


FIGURE 178. Radar photograph of hurricane "Donna" as observed at Key West, Fla., September 10, 1960.

RAINFALL

The rainfall pattern revealed in the radar photograph shown in figure 178 is typical of that of a mature hurricane. As previously discussed, liquid water gives the best return signals on a weather radar scope. The characteristic "spiral band" appearance of the rainfall distributed about a hurricane is evident through the white areas in the photograph. Individual convective showers and thunderstorms become aligned in this pattern about the center of the storm. The heaviest rainfall ordinarily is found in the semicircle to the right of the direction of movement of the hurricane, where accumulations have on occasions exceeded 40 inches in a 24-hour period. The appearance of the spiral band structure changes continually.

Heavy rainfall often continues after a hurricane has moved inland, even though the storm's wind circulation has decreased considerably.

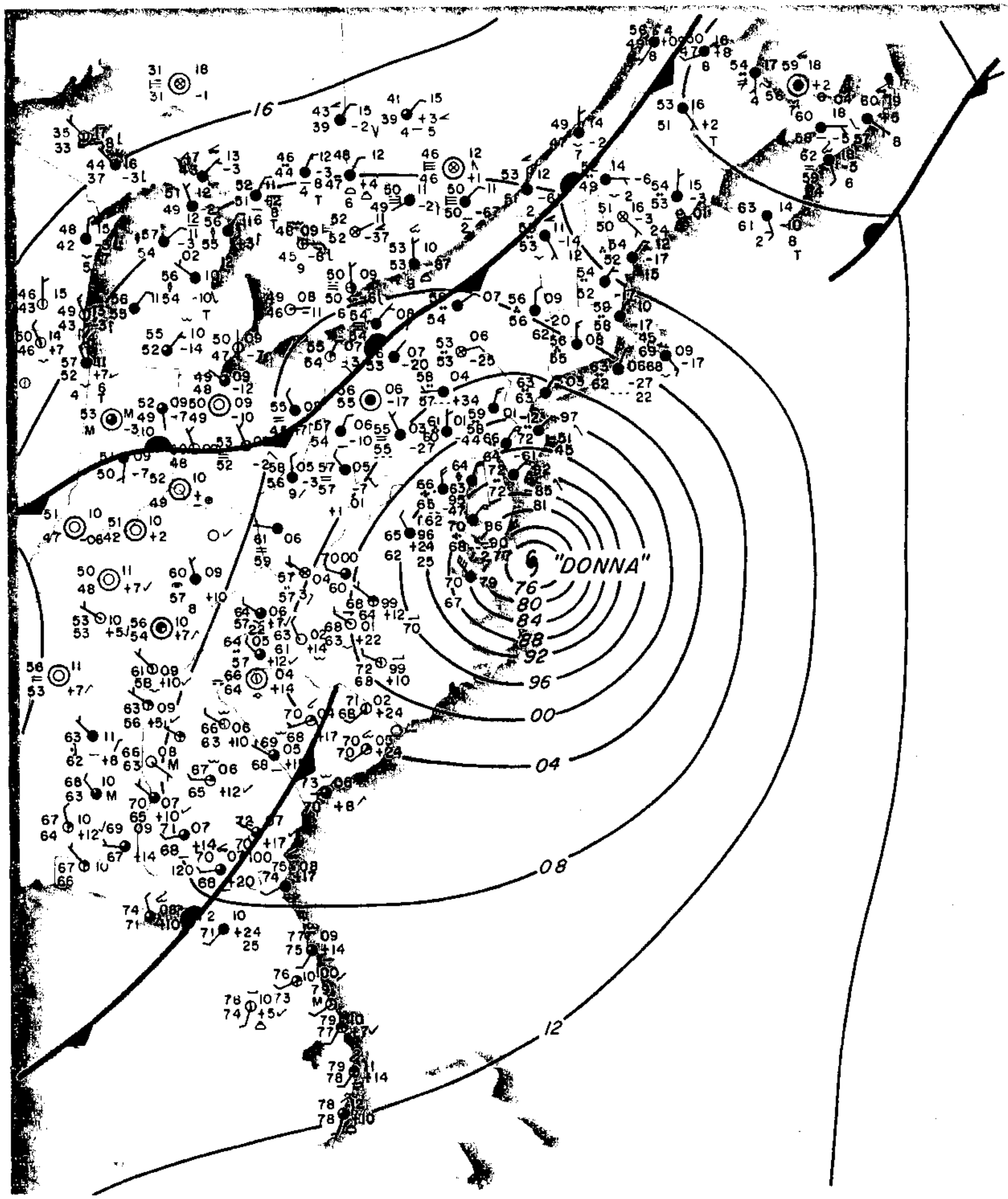


FIGURE 179. Hurricane "Donna" on the surface weather chart, 1200 GMT, September 12, 1960.

HURRICANE DAMAGE

Even though the torrential rainfall accompanying hurricanes often floods interior land regions, while the violent winds bring much destruction, the greatest loss of life and property is usually a result of inundation of coastal areas by rises in the level of the sea. These abnormally high tides are known as storm surges. They may be as much as 10 to 15 feet above normal tide; along the Atlantic and Gulf Coasts, their usual range above normal tide is from 4 to 12 feet. A storm surge which occurs at a time of day when the tide is normally high will cause much more flooding than it would at other times.

Hurricanes are the most destructive of all storms. Although tornadoes have winds which are even more violent, they are small storms compared to hurricanes. Some of the larger hurricanes have a diameter of up to about 1,000 miles, with destructive winds over an area as large as 500 miles in diameter (see fig. 179). Hurricanes can be much smaller than this, however. In some small but intense hurricanes, the path of destructive winds may not be wider than 25 miles.

An average of about eight tropical storms (including five hurricanes) threatens the contiguous States each year.

DECAY OF TROPICAL STORMS AND HURRICANES

Cooler surface temperatures and the accompanying loss of moisture, inflow of air (from land), and increased surface friction cause a tropical storm or hurricane to decay. During

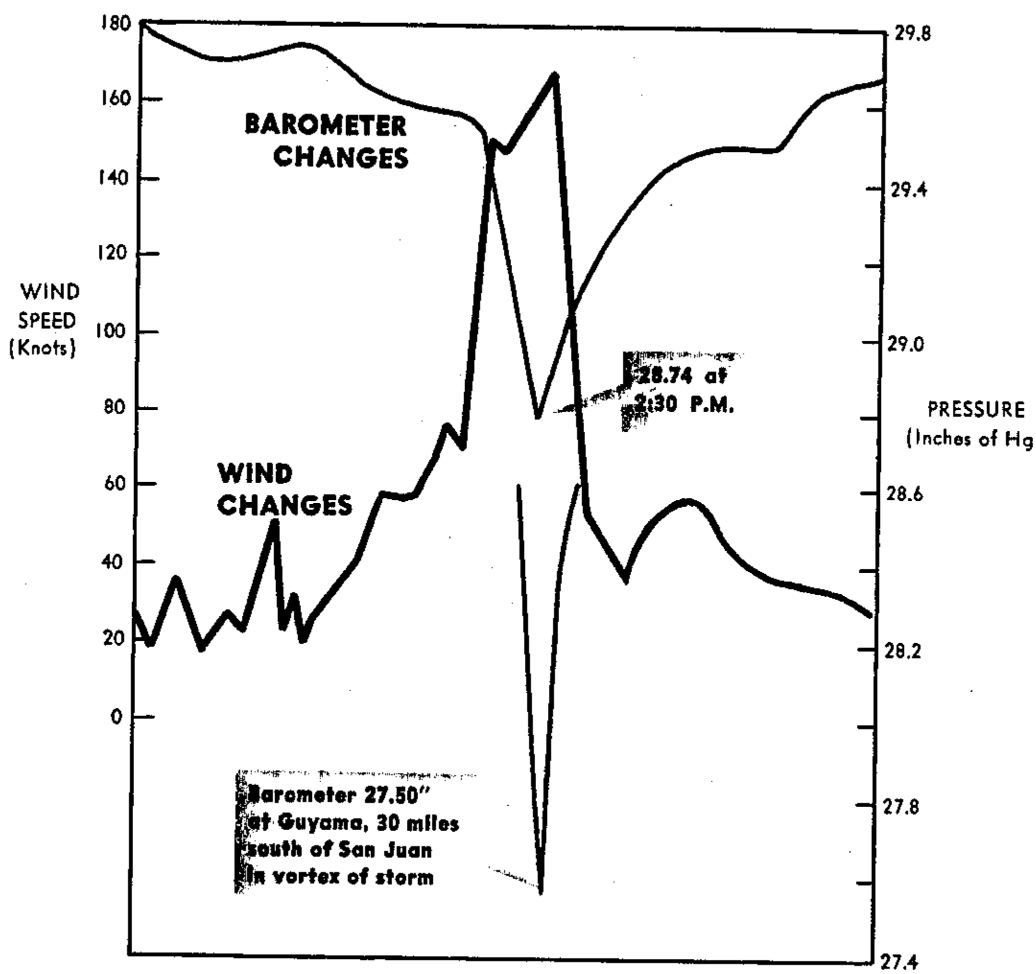


FIGURE 180. Changes in pressure and wind at San Juan, P. R. during a hurricane passage.

the period of movement when the storm curves toward the north or east, it usually begins to lose its tropical characteristics and acquires the characteristics of low pressure systems normally occupying the middle and high latitudes. The latter type of low pressure system is called "extratropical," meaning "outside the Tropics." Weather reconnaissance pilots have found the roughest flying weather in storms during the transition period between tropical and extratropical.

BAROMETRIC PRESSURE

The sea level atmospheric pressure nearly always falls below 29 inches in fully developed hurricanes, and there are records of many readings below 28 inches. The lowest recorded pressure in a hurricane over the United States was 27.61 inches at Miami, Fla., in September 1926. Figure 180 shows the changes in barometric pressure observed during the passage of a hurricane center near San Juan, P.R.

DETECTION AND WARNING OF TROPICAL CYCLONES

The Weather Bureau maintains a constant watch for the formation and development of tropical cyclones in the North Atlantic Ocean, Gulf of Mexico, west coast of the United States, and the North Pacific Ocean. A network of storm warning centers has been established near the seasonal tracks of these cyclones. These storm warning centers are equipped with long-range weather radar. Specially equipped weather reconnaissance aircraft are dispatched on demand to any area where weathermen suspect a tropical cyclone exists or may be forming. Cloud photographs transmitted from weather satellites have revealed tropical cyclones on some occasions when their existence would have been unknown otherwise (because of the scarcity of land and sea observational data in the area where they formed). On a number of occasions, weather satellites have detected tropical cyclones which were approaching foreign nations. In these cases, the Weather Bureau advises the foreign nation (s) of the existence and location of these threats to their safety and economy. Figure 181 is a satellite photograph of a hurricane. (See app. IV for photographs made from high altitudes of clouds associated with other weather phenomena.)

In a constant effort to improve the effectiveness of detection and tracking systems for tropical cyclones, the United States is experimenting with weather buoys which automatically transmit weather information to land stations and can be left unattended for extended periods of time.

In addition to detecting and tracking tropical cyclones, the storm warning centers forecast their intensity and movement. This information is disseminated to the general public and to all organizations that need it.

TROPICAL CYCLONES AND THE PILOT

All pilots except those specially trained to explore tropical storms and hurricanes should avoid these dangerous cyclones. Occasionally, jet aircraft have been able to fly over small and less intense storms, but the experience of weather research aircraft, flying at altitudes of 35,000 to 43,000 feet in the tops of hurricanes, shows that severe to occasionally extreme turbulence may be expected in well-developed hurricanes. Also, in the formative stages of tropical cyclones, a heavy concentration of thunderstorms may occur with tops exceeding 40,000 feet. In the case of lower-flying aircraft, circumnavigation may be accomplished by keeping the storm center to the left of the flight path (for a Northern Hemisphere storm). In this way, the aircraft will experience a tailwind component around the storm.

Until a hurricane begins to take on the characteristics of an extratropical storm, winds in a typical hurricane are strongest at low levels and decrease with elevation. However, winds in excess of 100 knots frequently have been measured by research aircraft at 18,000 feet, and the change to much lighter winds usually occurs at altitudes above 30,000 feet.

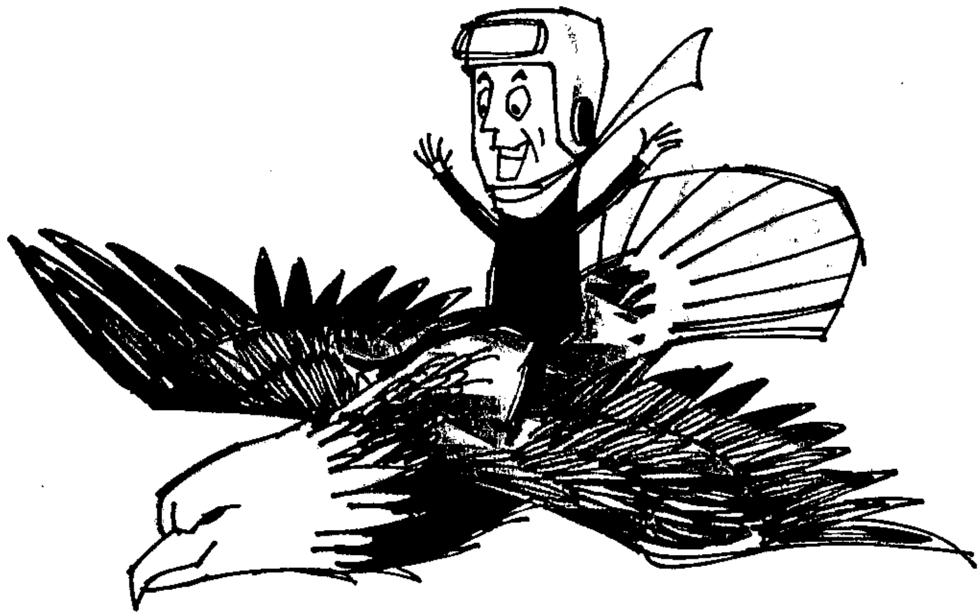
When flying a low-level flight in the vicinity of a tropical storm or hurricane, it is difficult to determine true altitude without the aid of a radio altimeter. Because of the large changes in pressure which occur across a hurricane area, the actual altitude may change several thousand feet while the *pressure* altimeter indicates flight

FIGURE 181. A satellite photograph of a hurricane.

at a constant altitude. In the case of one storm in 1960, a weather research aircraft entered the storm at 5,000 feet pressure altitude and held this pressure altitude throughout the storm crossing. However, the actual altitude, from the time the aircraft entered the storm area until it reached the center of the "eye," changed from 5,000 feet to 3,050 feet.

Some of the most severe turbulence is encountered in the surrounding wall of the "eye," within 10 miles or less of the "eye's" boundary. Other areas of turbulence are found within the spiral rain bands. Flight at low levels, say 500 to 3,000 feet above the surface, results in exposure to sustained, pounding turbulence due to the surface friction of the fast-moving air. These areas of turbulence are virtually impossible to define without airborne weather radar.

In deciding whether or not to fly near a hurricane, a pilot should consider the odds against surviving should the aircraft have to be ditched. It may be helpful to remember that the most intense part of the storm, and consequently the highest seas, are found in the right front quarter of the storm; the weakest portion is in the left rear quarter.



Chapter 22
SOARING WEATHER

Sailplanes use rising columns of air or larger-scale upgliding motions of air for motive power. Once the sailplane is airborne, soaring depends on the availability of free lift and the pilot's effective use of it. Most soaring is done during daylight and in good weather.

Soaring has made notable contributions to meteorology. For example, sailplanes have been used for systematic research probing of thunderstorms and mountain waves, with results that have made flying safer for all pilots because of their findings. Many a power pilot has gained considerable weather knowledge through glider training and experience.

The upward motion of air, called "convection," may be caused by density differences within the atmosphere (free convection or lifting as a result of heat), or mechanical lifting (forced convection by frontal lifting, orographic lifting, or convergence). The lift experienced by the sailplane frequently is a combination of these two basic types.

THERMALS PRODUCED BY SOLAR HEATING

Convective currents produced when the sun heats the earth (ch. 7) are the most common source of lift provided by nature. Called "thermals" in soaring terminology, these currents are used universally by sailplane pilots for gaining altitude and for sustaining flight.

As the Earth is heated by the sun, it in turn heats the air near the ground, making it lighter and thus more buoyant than the air surrounding it. The lighter air rises until it reaches an altitude where its temperature is the same as the air surrounding it. There, vertical motion ceases, and the formerly warmer and lighter air comes to rest.

In some cases, the rising air current may be limited by a temperature inversion aloft. If there is sufficient moisture in the rising air, cumulus clouds form when the air reaches an altitude where its temperature has cooled to the dew point temperature. Cumulonimbus and large or rapidly growing cumulus clouds indicate the absence of a temperature inversion, and fairly strong updrafts may extend into the clear air well above the cloud tops.

Most thermals consist of a series of large bubbles of heated air which follow one another at intervals ranging from a few minutes to an hour or more (see fig. 182). These air bubbles may be compared to those rising from the bottom of a pot of gently boiling water. The amount of surface heating is not sufficient to supply a continuous column of rising air, and the heated air which accumulates over an area is released in surges, with "air bubbles" accelerating upward like balloons. Near the heated surface, the warm air between bubbles is consumed quickly by other bubbles forming simultaneously. Cooler air from above sinks between the bubbles, pinching them off. This sinking air between thermals may be used by the pilot to increase his rate of descent, but its downward speed is not nearly so great as the rate of lift in the average thermal.

Vertical speeds in thermals range from more than 20 feet per second to insufficient speeds to sustain a sailplane, depending on the initial strength and stage of the thermal when it is encountered. Fairly well-developed thermals have vertical speeds averaging 10 feet per second.

Thermals are strongest where the air near the ground is most heated. Thus, this source of lift for soaring is most effective on warm summer days and over barren, rocky soil or sandy areas. Plowed fields are fairly effective in forming thermals, while areas of vegetation usually are less productive. The moisture content of the air

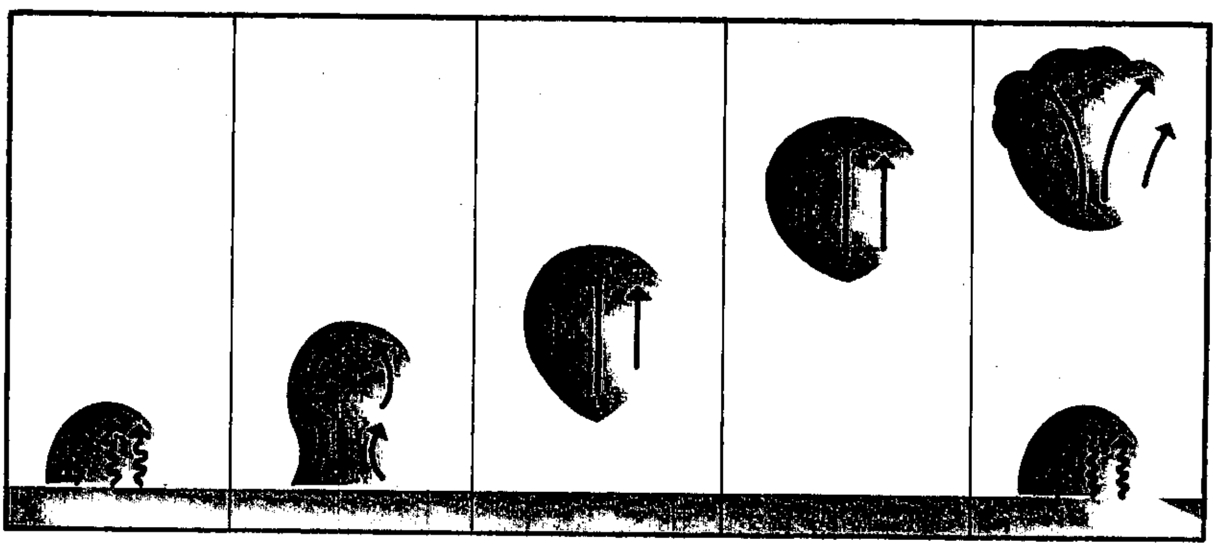


FIGURE 182. Progressive stages of a thermal bubble.

can be important in creating buoyant forces, since moist air is lighter than dry air.

The most frequently used technique for distance soaring is to find a fairly strong thermal, use it as long as it lasts or until the desired height is gained, and then fly on course until another thermal may be used to regain altitude (see fig. 183). For maximum distance, it is necessary to fly downwind, requiring knowledge of winds at various flight levels.

Early afternoon, without overcast skies, is the time of greatest solar heating and, therefore, the best time for thermals to form. Thermals may form at other times, but only when a temperature has been reached at the bottom of the air layer that will result in an unstable lapse rate (ch. 6) and "trigger" their formation. The time of day that the triggering temperature will be reached varies with a number of meteorological factors, such as the characteristics of the air mass over the area, the amount of cloudiness, the strength of the wind flow, and the vertical distribution of temperature. Surfaces which heat most during the day also cool more by radiation at night. On the same type of ground surface, thermals begin to form first over hills, peaks, and mountain slopes because the triggering temperature at any higher elevation is reached sooner than it is at a lower elevation having the same amount of cloudiness and wind. For example, if thermals form in dry air at 6,000 feet at 81° F., the temperature needed to trigger them at 5,000 feet will be 86½° F. because of the dry adiabatic lapse rate (5½° F. per 1,000 feet) (see fig. 184). Also, thermals form first at higher elevations because rays from the sun strike hills and slopes during the morning at more nearly perpendicular angles than they strike flat land areas, thus heating the higher elevations faster (also illustrated in fig. 184).

The horizontal cross section of a thermal is more or less circular. Near the ground, diameters vary from a few yards to several hundred yards. Diameters tend to increase as they rise and are largest when the wind is light. Thermals may tilt with an increase in wind with altitude. In some cases, the wind will move the entire thermal from its source. When the wind speed is 15 knots or more, thermals tend to break into segments.

The thunderstorm (ch. 11), sometimes defined as the ultimate manifestation of the growth of a cumulus cloud, represents atmospheric thermal convection at its strongest. Thunderstorms which form isolated from one another within air masses (ch. 9) are triggered usually by heating of air by the earth's surface. (Other causes of thunderstorms are mentioned later in this

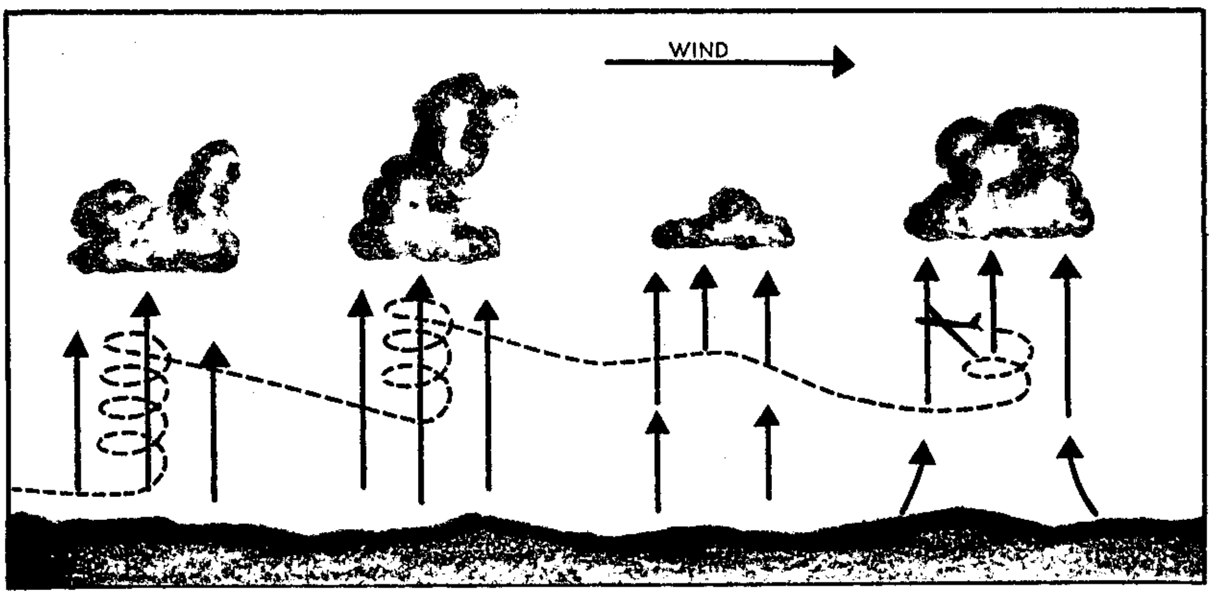


FIGURE 183. Using thermals and prevailing wind for distance soaring.

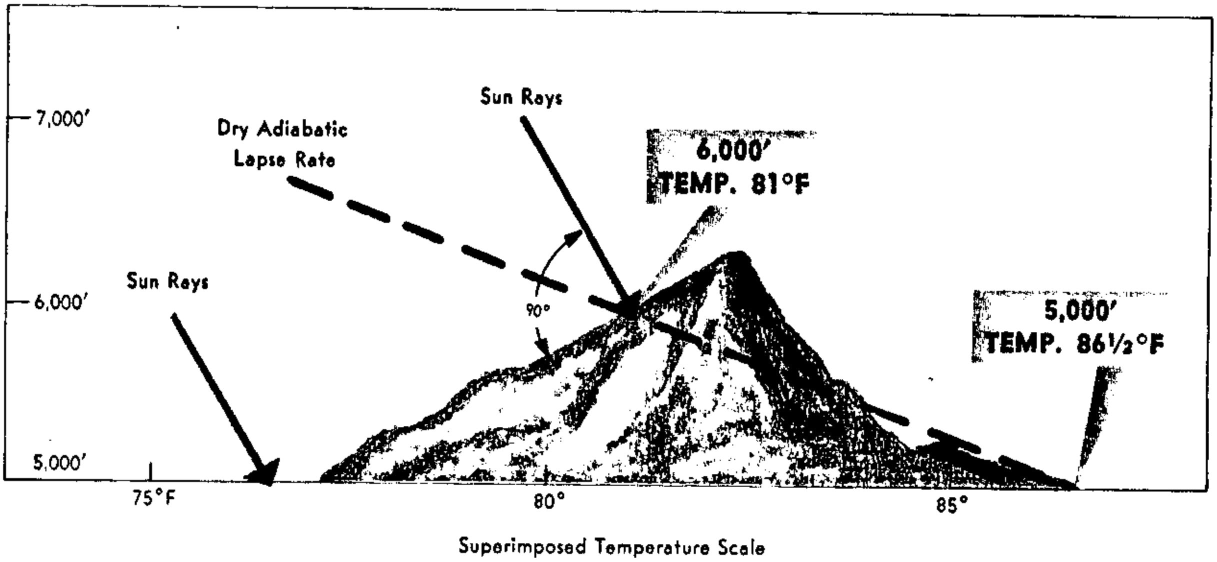


FIGURE 184. Thermal triggering temperatures are higher at low elevations.

chapter.) The updrafts associated with thunderstorms are very strong and tempt sailplane pilots wanting to gain altitude. Some pilots use them to advantage by cruising just ahead of the storm while trying, at the same time, to avoid engulfment by the storm cloud. It is possible to get under a thunderstorm or a large cumulus cloud and get sucked up into it—a very hazardous situation. Regardless of origin, thunderstorms are extremely hazardous to sailplanes as well as to power aircraft. Their vertical velocities sometimes exceed 200 feet per second, imposing stresses which few, if any, aircraft can stand. Hail and wing icing are other possible hazards. The novice should avoid thunderstorm areas.

OTHER THERMALS FORMED NEAR THE GROUND

Thermals somewhat similar to those caused by solar heating sometimes result from manmade effects. Sailplane pilots find that industrial smokestacks often produce a localized and continuous type of updraft that, with light winds, may extend upward for several thousand feet. Such thermals are found over steel mills, brick kilns, and certain types of fuel-burning electric power generating plants. Since these thermals are not as wide as those produced by nature, it is more difficult to circle within them.

Any source of heat can produce thermals. For example, burning of dry foliage on a farm field may cause thermals to form. A larger-scale updraft is caused by extensive forest fires. Sailplane pilots sometimes serve as aerial forest fire observers during prolonged periods of motorless flight.

Dust devils produce strong lift but can be very violent. Easily visible to the pilot, they should never be entered below 500 feet above the ground, and it is safer to avoid them entirely.

INSTABILITY ALOFT

Convective activity also occurs in relatively shallow, unstable layers aloft, often at heights of more than 8,000 feet. These unstable layers are caused by cold air moving in above warmer air, or by warmer air moving in below the cold air. In either case, the lapse rate in the boundary zone between the cold and warm air increases, and, if instability is present (see fig. 185), the air begins to overturn. Instability aloft, which may be present at any time of the year, is revealed by atmospheric soundings (ch. 15) and often is marked by altocumulus clouds (ch. 8).

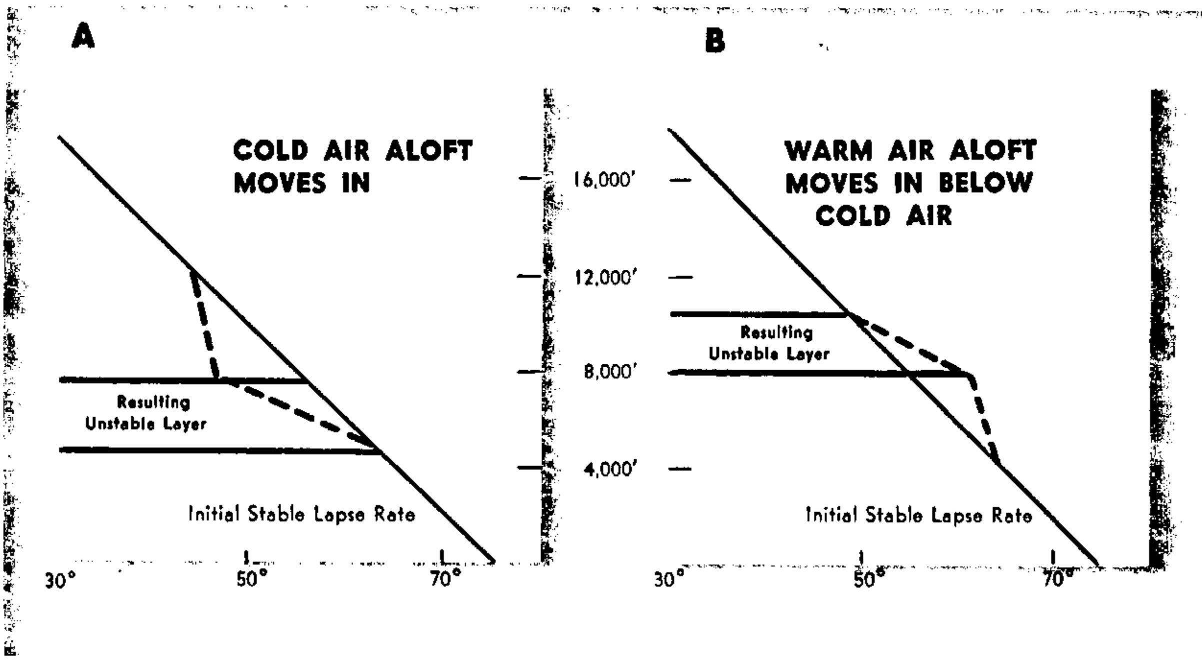


FIGURE 185. Instability aloft.

MECHANICAL OR FORCED LIFTING OF AIR

OROGRAPHIC LIFT

Lift Over Ridges and Windward Slopes. Early attempts at soaring used mostly the drafts on windward slopes of mountains and near the crests of hills and ridges.

There must be a component of wind flow against a mountain ridge to result in lifting of air, and the greatest lift of this type occurs when the wind blows directly against the ridge. Lifting diminishes as the wind flow becomes parallel to the ridge, but the strength of the rising currents depends largely on the speed of the wind and the slope profile. The steepness of the slope naturally is important, as well as terrain irregularities.

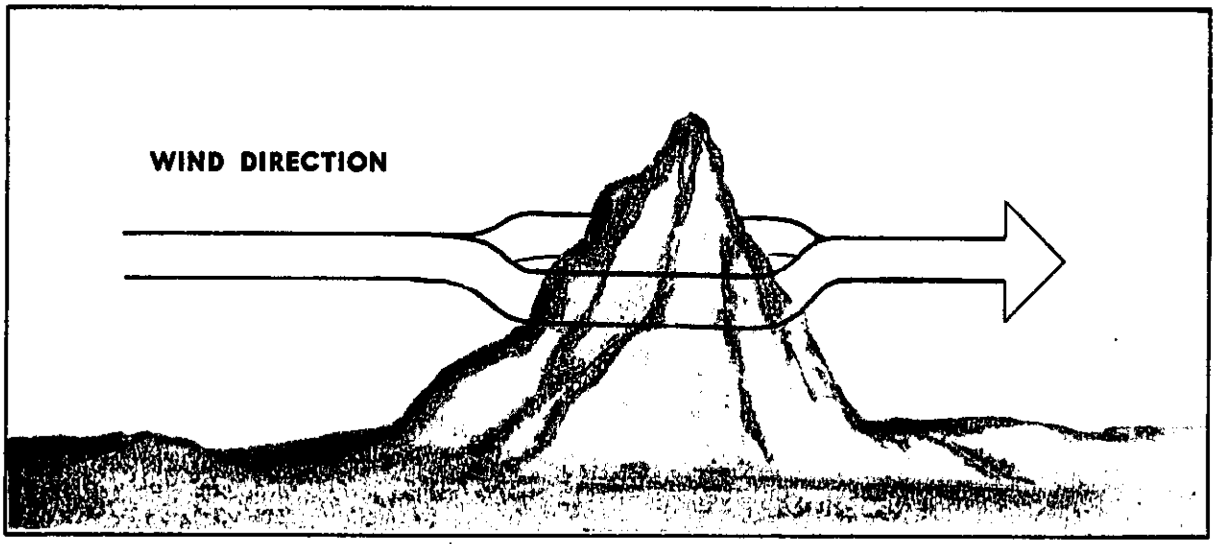


FIGURE 186. Flow of wind around a mountain peak.

Ridges having elevation changes of several hundred feet normally are most favorable for soaring. The effect of the slope steepness is difficult to assess because, if the slope is too steep, turbulent eddies often develop on the leeward as well as the windward side of the ridge. Ridges extending for several miles without abrupt breaks tend to provide uniform lift throughout their length. In contrast, wind flow in the vicinity of a single peak is largely diverted around the peak rather than over it, and thus is not favorable for soaring (see fig. 186).

Some of the wind flow patterns that occur over ridges of different forms are shown in figure 187. There are many deviations from these patterns, depending on wind speed, slope profile, and general terrain roughness. Uneven surface slopes produce many irregular currents or eddies. Only the general configurations of these eddies can be described, but areas where the flow is likely to be most disturbed can be indicated by the forecaster. Eddies tend to form more readily when the air is stable. The rambling and unsteady turbulence found with a dry adiabatic lapse rate seems to inhibit eddies, which are irregularities of smaller scale.

Even a moderate slope can support soaring. For example, with a ridge slope of 1 to 4 and a wind against it of 15 knots, the lift is 3¾ knots, or about 6 feet per second, which is enough for an intermediate-type sailplane. With the same ridge slope, a high-performance sailplane with a sinking speed of 2 feet per second theoretically would require only 6 knots of wind.

Thermals on the windward side of a ridge have their lift increased by the lift resulting from the upslope effect.

MOUNTAIN (STANDING) OR LEE WAVES

Mountain or "standing" waves are large-scale disturbances in the horizontal air flow, which under certain conditions develop either singly or in a series downstream to the lee of mountain ridges. They remain about stationary, with the wind blowing through them, and may be compared to the flow of water through a series of waves formed downstream from a submerged rocky ridge in a creek or river.

FIGURE 187. Flow of wind over various types of terrain.

Air dips sharply downward immediately to the lee of a ridge, before rising and falling in a wave motion for a considerable distance downstream (see fig. 188). (Fig. 37 in ch. 7 is another illustration of a mountain wave.) The wavelength (indicated in fig. 188), the distance between the crests of successive waves (usually between 2 and 20 miles), is controlled by the wind component perpendicular to the ridge and the vertical distribution of temperature in the upstream flow. Normally it is greater than the distance between the ridge crest and the first wave crest. The shorter the wavelength, the steeper the ascents and descents of air.

The vertical dimension (amplitude) of the wave, half the altitude difference between the wave trough and crest (also indicated in fig. 188), varies with height above the ground. The wave amplitude is small near the ground and at very high levels. In a typical wave, the greatest amplitude is roughly 3,000 to 6,000 feet above the ridge crest elevation. The wave amplitude is controlled by the size, shape, and type of surface of the ridge, as well as the wind and vertical temperature distribution in the airstream. The larger the amplitude, the farther the air moves up and down.

When a mountain wave condition exists, usually a stable layer of air is found several thousand feet above the ridge crest, and winds increase with height across the ridge. A shallow layer of great stability produces larger wave amplitude than a deep layer of moderate stability. The stronger the wind, the faster the air moves through the wave pattern. Therefore, mountain waves offering best sources of lift are those having (1) large amplitude, (2) short wavelength, and (3) strong winds.

If the air is humid and the wave is of large amplitude, lenticular (lens-shaped) clouds mark the wave's crests. Air in the updraft cools and, if the moisture content is sufficient, clouds form, while warming in the downdraft evaporates the cloud. Thus, by continuous condensation on the windward side and dissipation on the lee side, the cloud appears to be stationary. A wave cloud does not necessarily indicate a large amplitude or strong updrafts because humid air reaches its condensation level in less vertical distance than drier air.

Soaring conditions in mountain waves often are remarkably smooth, but at times are *extremely* turbulent. This is largely due to the variation in amplitude with height and the amount of wind shear created by increasing wind speeds with height. However, turbulence often amounts to no more than shallow patches of rough air between smooth layers. Areas of

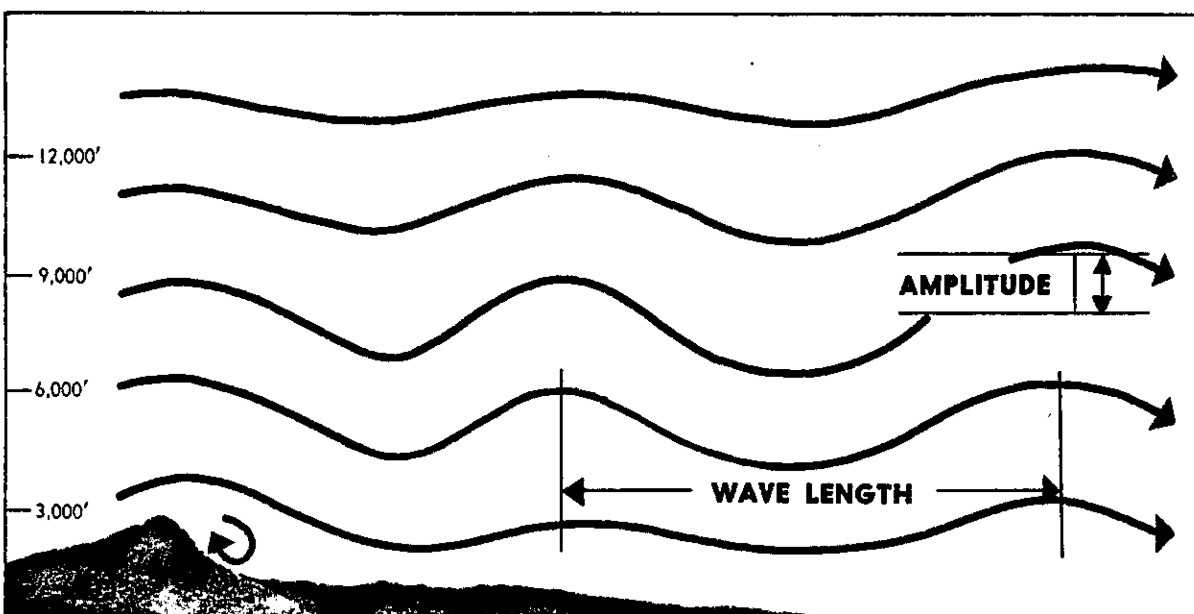


FIGURE 188. A mountain wave.

strong lift in waves sometimes are so smooth that they are almost ghostly. But even weak waves can trigger turbulence in the strong wind shears associated with jet streams (ch. 19). Also, when the amplitude varies considerably with height, the turbulence may be quite violent—about as violent as that found anywhere in the atmosphere. In such cases, the wave cloud (if present) is ragged and tattered with fragments torn from the trailing edge. The top of the cloud moves much faster than the base in these situations, resulting in the term "roll cloud" in association with this rotor flow (see fig. 37). The maximum lift is on the windward side of any rotors which may form.

Local thermal convection can intensify the roll cloud turbulence. If the humidity is low, no cloud may be present, but the turbulence may be just as violent in the rotor flow. This is a serious hazard to aircraft attempting to climb into the wave. But once in the wave itself, sustained flight and great gains of height are possible on the upwind side and parallel to the wave crest. Sailplanes have attained altitudes above 46,000 feet in these waves, and pilots sometimes use the jet stream for distance flights.

FRONTAL LIFT

Chapter 10 provides a detailed discussion of fronts, but a few points need reemphasizing.

Since slopes of cold fronts normally are steeper than those of the warm and occluded type, cold fronts offer the best sources of frontal lift. However, they cause more weather hazards. Thunderstorms often form as squall lines ahead or in cold fronts (see ch. 11). While soaring updrafts may be found near or a few miles ahead of such fronts and squall lines, soaring is dangerous if there is a cloud shield that obscures the weather hazards.

The sea breeze over coastal hills and islands often is excellent for soaring (ch. 4). When the general wind flow in the lower levels is light, a local wind is produced due to radiative temperature changes (which are more rapid over land areas than water surfaces). As the land surface is heated during the day, the resulting lighter air near the ground causes a sea level pressure difference (gradient) between the sea and land. The colder air over the water moves toward the lower pressure, forcing the warm air over the land upward. The onshore wind thus created is called a "sea breeze."

As the onshore winds push comparatively cold air under warm air, the resulting weather is similar to that produced by a weak cold front. "Sea breeze front" is a familiar term in many coastal areas. Southern California and parts of the Hawaiian Islands are examples of almost ideal places for sea breeze front soaring because orographic lift is added to the weak frontal action. Sea breezes normally reach lee or inland sides of hills and mountains, unless the mountains are high and long without abrupt breaks. In the latter case, the sea breeze front converges on the windward slope. Where hills and mountains are fairly low, sea breezes may penetrate inland for surprising distances. In the Tropics, they sometimes penetrate 150 miles, while 50 miles is unusual in the midlatitudes. The penetration depends on (1) the duration and strength of the sunshine, (2) the depth of the heated layer of air, (3) the strength and direction of the general wind flow, and (4) the sea temperature.

Since the sea breeze front is not always marked by clouds, sailplane pilots often are not aware of the updrafts near its leading edge. Sometimes the front may be located by the contrast between the hazy sea air and the clearer air inland. In southern California, the leading edge of the sea breeze front is marked by polluted air, locally called the "smog front."

COMBINED HEAT AND MECHANICAL SOURCES OF LIFT

From the preceding discussion, it probably is apparent that sources of lift frequently are neither purely thermal nor purely mechanical. As mentioned before, thermals on windward slopes or over crests of ridges and hills provide more lift than those over flat land. Whenever air comes together from different directions, it must go up. This is "convergence", a condition found in low pressure troughs and fronts, including the sea breeze front. The area or line of convergence is also a fertile region for thermal formation.

Thermal considerations always are involved in the extent of lift produced by mechanical sources. Even the lift in mountain waves varies diurnally. Usually mechanical and heat lift work together, but convection may suppress or sometimes even obliterate soarable mountain waves.

ILLUSTRATIONS

Figure | Page

GLOSSARY OF METEOROLOGICAL TERMS

ACTIVE FRONT. A front which produces considerable cloudiness and precipitation.

ADIABAT. A line or curve on a temperature-pressure diagram along which a thermodynamic change takes place without the gain or loss of heat.

ADIABATIC PROCESS. A thermodynamic process in which no heat is given to or withdrawn from the body of air concerned. Adiabatic changes of atmospheric temperature are those that occur only as a result of compression or expansion accompanying an increase or a decrease of atmospheric pressure. Such changes are also described as dynamic heating and cooling.

ADVECTION. The transfer of atmospheric properties by horizontal movements of air. The term is used most commonly in reference to transfer of heat.

AEROLOGY. As a subdivision of meteorology, the study of the free atmosphere throughout its vertical extent.

AIR MASS. An extensive body of air having the same properties of temperature and moisture in a horizontal plane.

ALTIMETER. An aneroid barometer calibrated to indicate altitude instead of pressure.

ALTIMETER SETTING. Pressure in inches of mercury converted to make the altimeter read zero elevation at an altitude of 10 feet (average cockpit height) above mean sea level, or to read field elevation 10 feet above the runway.

ALTOCUMULUS. A form of middle cloud.

ALTOSTRATUS. A form of middle cloud.

ANEMOMETER. An instrument for measuring the speed of the wind.

ANEROID BAROMETER. An instrument for measuring atmospheric pressure.

ANTICYCLONE. An area of high pressure.

ANVIL CLOUD. A heavy cumulus or cumulonimbus with an anvil-like form in its upper portions.

ATMOSPHERE. The envelope of air surrounding the earth.

ATMOSPHERIC PRESSURE. The force exerted by the weight of the atmosphere per unit area.

AURORA. A luminous phenomenon due to electrical discharges in the atmosphere; probably confined to the thin air of high altitudes. Most commonly seen in sub-Arctic and sub-Antarctic latitudes, it is called aurora borealis or aurora australis, according to the hemisphere where it occurs. Observations with the spectroscope indicate that a faint "permanent aurora" is a normal feature of the sky in all parts of the world.

BACK. Of the wind, to shift in a counterclockwise direction; opposite of veer. In scientific practice, this definition now applies to both hemispheres.

BAROGRAPH. A self-recording aneroid barometer.

BAROMETER. An instrument for measuring the pressure of the atmosphere. The two principal types are the mercurial and the aneroid. The microbarometer is used to show very small changes of pressure.

BAROMETRIC TENDENCY. The changes of atmospheric pressure within a specific time (usually 3 hours) before the observation.

BLIZZARD. A violent, intensely cold wind, laden with snow.

BUYS BALLOT'S LAW. If an observer in the Northern Hemisphere stands with his back to the wind, lower pressure will be on his left.

CALM. The absence of apparent motion of the air.

CEILING. The height ascribed to the lowest layer of clouds or obscuring phenomena when the sky is reported as broken, overcast, or obscured and the clouds are not classified "thin" or "partial." The ceiling is termed unlimited when the foregoing conditions are not present.

CELSIUS. A temperature scale identical to the Centigrade scale, with 0° as the melting point of ice and 100° as the boiling point of water.

CHINOOK, OR CHINOOK WIND. A foehn blowing down the eastern slope of the Rocky Mountains over the adjacent plains, in the United States and Canada. In winter, this warm, dry wind causes snow to disappear with remarkable rapidity, and hence it has been nicknamed the "snoweater."

CIRROCUMULUS. A form of high cloud.

CIRROSTRATUS. A form of high cloud.

CIRRUS. A form of high cloud.

CLIMATE. The prevalent or characteristic meteorological conditions of any place or region, and their extremes.

CLIMATOLOGY. The study of climate.

CLEAR AIR TURBULENCE. Turbulence encountered by aircraft in air space that is devoid of clouds, regardless of the cause.

CLOUD. A visible cluster of minute water and/or ice particles in the atmosphere above the earth's surface.

CLOUD BANK. A well-defined mass of clouds observed at a distance. It covers a considerable portion of the horizon sky, but it is not overhead.

CLOUDBURST. A sudden and heavy fall of rain, almost always of the shower type.

COLD FRONT. The discontinuity at the forward edge of an advancing cold air mass which is displacing warmer air in its path.

COLD WAVE. A rapid and marked fall of temperature. The Weather Bureau applies this term to a fall of temperature in 24 hours equaling or exceeding a specified number of degrees and reaching a specified minimum temperature or lower. These specifications vary for different parts of the country and for different periods of the year.

CONDENSATION. The process by which a vapor becomes a liquid.

CONDENSATION LEVEL. The height at which a rising column of air reaches saturation, and clouds form.

CONDENSATION NUCLEI. Small water-absorbent particles in the air on which water vapor condenses or sublimates.

CONDITIONAL STABILITY (or Conditional Instability). The state of a column of air when its vertical distribution of temperature is such that the layer is stable for dry air, but unstable for saturated air.

CONDUCTION. The transfer of heat by molecular action.

CONSTANT PRESSURE CHART. A chart which usually contains plotted data and analysis of the distribution of heights of any selected isobaric surface, and the analyses of the wind, temperature, and humidity existing at each height of the selected isobaric surface.

CONTRAIL. A cloud-like streamer frequently observed behind aircraft flying in clear, cold, humid air caused by the addition to the atmosphere of water vapor from engine exhaust gases.

CONVECTION. Vertical air movements resulting in the transport of atmospheric properties.

CONVECTIVE INSTABILITY (Also called POTENTIAL INSTABILITY). The state of an unsaturated layer or column of air in the atmosphere whose wet-bulb potential temperature (defined later) decreases with elevation. If such a column is lifted bodily until completely saturated, it will become unstable (i.e., its temperature lapse rate will exceed the moist adiabatic lapse rate) regardless of its initial degree of stability.

CONVERGENCE. The condition that exists when the distribution of winds within a given area results in a net horizontal inflow of air into the area. In convergence at lower levels, the removal of the resulting excess is accomplished by an upward movement of air; consequently, areas of convergent winds are regions favorable to the occurrence of precipitation.

CORIOLIS FORCE. A deflecting force normal to the velocity, to the right of motion in the Northern Hemisphere and to the left in the Southern Hemisphere. It cannot alter the speed of the particle. Coriolis force tends to balance the pressure gradient between highs and lows and to cause the air to move parallel to the isobars above ground friction levels.

CUMULIFORM. Descriptive of clouds having dome-shaped upper surfaces which exhibit protuberances.

CUMULONIMBUS. A form of cloud with extensive vertical development.

CUMULUS. A form of cloud with less vertical development than cumulonimbus.

CYCLOGENESIS. The process which creates or develops a new cyclone; also, the process which produces an intensification of a preexisting cyclone.

CYCLONE. An area of low atmospheric pressure that has closed circulation. Tropical cyclones are smaller, on an average, than those of higher latitudes, and in many cases are the most violent of all storms, except tornadoes. Cyclones occurring in higher latitudes (extratropical cyclones), regardless of their source of origin, usually bring about marked changes of weather and temperature during their passage; their winds may be extremely high. Tropical cyclones are also called hurricanes (when violent), typhoons, or baguios. Extratropical cyclones are commonly known as lows or depressions.

DEEPENING. The occurrence of decreasing pressure in the center of a low pressure system.

DENSITY. The mass of a substance per unit volume. The density of a gas is particularly sensitive to changes in temperature (and pressure). The weight of a substance varies directly with its density.

DEPRESSION. A cyclonic area, or low.

DEW. Atmospheric moisture condensed as liquid upon objects cooler than air.

DEW POINT. The temperature to which air must be cooled, at constant pressure and moisture content, in order for saturation to occur.

DISCONTINUITY. A zone with comparatively rapid transition of meteorological elements.

DIURNAL. Daily, especially pertaining to actions which are completed within 24 hours, and which recur every 24 hours.

DIVERGENCE. The condition that exists when the distribution of winds within a given area results in a net horizontal flow of air outward from the region. In divergence at lower levels, the resulting deficit is compensated for by a downward movement of air from aloft; consequently, areas of divergent winds are regions unfavorable to the occurrence of precipitation.

DOLDRUMS. The equatorial belt of calms or light variable winds, lying between the two trade-wind belts.

DRIZZLE. Precipitation from stratus clouds consisting of numerous tiny droplets.

DRY BULB. A name given to an ordinary thermometer used to determine the temperature of the air, in order to distinguish it from the wet bulb.

EDDY. A whirl or circling current of air or water, different and differentiated from the general flow.

EVAPORATION. The transformation of a liquid to the gaseous state. Heat is lost by the liquid during this process.

FAHRENHEIT. A temperature scale on which 32° denotes the temperature of melting ice, and 212° the temperature of boiling water, both under standard atmospheric pressure.

FALL WIND. A wind blowing down a mountainside; or any wind having a strong downward component. Fall winds include the foehn, mistral, bora, etc.

FALSE CIRRUS. Cirruslike clouds at the summit of a thunder cloud; more appropriately called "thunderstorm cirrus."

FILLING. The occurrence of increasing pressure in the center of a low pressure system. Filling is the opposite of deepening.

FOEHN. A dry wind with strong downward component, warm for the season, characteristic of many mountainous regions. In the Rocky Mountains, it is called a chinook.

FOG. A cloud at or near the earth's surface. Fog consists of numerous droplets of water, which individually are so small that they cannot readily be distinguished by the naked eye.

FRONT. The zone of transition between two air masses of different density.

FRONTOGENESIS. The beginning or creation of a front.

FRONTOLYSIS. The destruction and dying of a front.

FROST. Crystals of ice formed like dew, but at a temperature below freezing.

GLAZE. A coating of ice, generally clear and smooth, but containing some air pockets. Synonymous with clear ice, it forms on exposed objects by the freezing of supercooled water deposited by rain, drizzle, fog, or possibly condensed from supercooled water vapor.

GRADIENT. Change of value of a meteorological element per unit of distance. The gradient most commonly discussed in meteorology is the horizontal gradient of pressure.

GUST. A sudden, brief increase in the speed of the wind.

HAIL. Precipitation consisting of balls of irregular lumps of ice often of considerable size; a single unit of hail is called a hailstone. Large hailstones usually have a center surrounded by alternating layers of clear and cloudy ice. Hail falls almost exclusively in connection with thunderstorms. The largest hailstone observed in the United States was 17 inches in circumference and weighed 1½ pounds.

HAZE. Fine dust or salt particles scattered through a portion of the atmosphere. Particles are so small that they cannot be seen individually, but they diminish horizontal visibility.

HIGH. An area of high atmospheric pressure that has closed circulation; an anticyclone.

HOARFROST. (See frost.)

HUMIDITY. The measure of water vapor content in the air.

HURRICANE. A tropical cyclone with wind speeds of 64 knots or greater.

HYGROGRAPH. A self-recording hygrometer.

HYGROMETER. An instrument for measuring the humidity of the air.

ICE NEEDLES. Thin crystals or shafts of ice, so light that they seem to be suspended in the air.

ICE STORM. (See glaze.)

INSOLATION. Solar radiation received at the earth's surface.

INSTABILITY. A state in which the vertical distribution of temperature is such that an air particle, if given either an upward or a downward impulse, will tend to move away with increasing speed from its original level.

INTERTROPICAL FRONT. The boundary between the trade wind systems of the Northern and Southern Hemispheres. It manifests itself as a fairly broad zone of transition commonly known as the doldrums.

INVERSION. A layer in which the temperature increases with altitude.

ISOBAR. A line of equal or constant pressure.

ISOTACH. A line of equal or constant wind speed.

ISOTHERM. A line of equal or constant temperature.

JET STREAM. A narrow meandering stream of winds with speeds of 50 knots and greater, embedded in the normal wind flow aloft.

LAND AND SEA BREEZES. The breezes that, on certain coasts and under certain conditions, blow from the land by night and from the water by day.

LAPSE RATE. The rate of decrease of an atmosphere variable with height, the variable being temperature unless otherwise specified.

LENTICULAR CLOUD. A cloud having approximately the form of a double-convex lens or almond.

LIGHTNING. A sudden flash of light caused by electrical discharges produced by thunderstorms.

LOW. An area of low atmosphere pressure, also a depression or cyclone.

METEOROLOGY. The study dealing with the phenomena of the atmosphere.

MICROBAROGRAPH. An instrument which records very small and rapid variations of atmospheric pressure.

MILLIBAR. A unit of pressure equal to a force of 1,000 dynes per square centimeter.

MIST. A popular expression for drizzle.

MONSOON. A wind that reverses its direction with the season, blowing more or less steadily from the interior of a continent toward the sea in winter, and in the opposite direction in the summer.

NIMBOSTRATUS. A form of middle cloud.

NOCTILUCENT CLOUDS. Clouds of unknown composition which occur at great heights.

NOCTURNAL. Occurring during the hours between sunset and sunrise.

NORMAL. The average value of a meteorological element over any fixed period of years that is recognized as standard for the country and for the element of concern.

OCCLUDED FRONT OR OCCLUSION. The front that is formed when and where a cold front overtakes a warm front or a stationary front.

OZONE. A nearly colorless (but faintly blue) gaseous form of oxygen with a characteristic odor like that of weak chlorine. It is found in trace quantities in the atmosphere, primarily above the tropopause.

PILOT BALLOON. A small balloon which indicates the movements of the air aloft by its drift—as observed from the ground.

POLAR AIR. Cold air having its source in the polar regions.

POLAR FRONT. The frontal zone between air masses of polar and those of tropical origin.

PRECIPITATION. The collective name for moisture in liquid and solid form large enough to fall from the atmosphere.

PRESSURE. (See atmospheric pressure.)

PRESSURE GRADIENT. The change in atmospheric pressure per unit of horizontal distance.

PREVAILING VISIBILITY. The greatest horizontal visibility which is equaled or surpassed throughout half of the horizon circle; it need not be a continuous half.

PREVAILING WIND. The wind direction most frequently observed during a given period.

PSYCHROMETER. An instrument for measuring atmospheric humidity, consisting of a dry-bulb thermometer and wet-bulb thermometer (covered with a muslin wick); used in the calculation of dew point and relative humidity.

RADIATION. Travel of electromagnetic waves at 186,000 miles per second, many of which may be visible as light. Cosmic rays, gamma rays, X-rays, ultra-violet rays, visible light rays, infra-red rays, and radio waves are some common types of radiation.

RADIOSONDE. A device carried aloft by a balloon equipped with measuring instruments that automatically convert temperature, pressure, and humidity data into electrical impulses and transmit this information to a ground recorder.

RAINBOW. A luminous arc formed by the refraction and reflection of light in drops of water.

RAINFALL. A term sometimes synonymous with rain, but most frequently used in reference to amounts of precipitation (including snow, hail, etc.).

RAIN GAGE. An instrument for measuring rainfall.

RELATIVE HUMIDITY. The ratio of the amount of moisture in the air to the amount which the air could hold at the same temperature if it were saturated; usually expressed in percent.

RIDGE. An elongated area of relatively high pressure extending from the center of a high pressure region.

RIME. A milky and opaque granular deposit of ice formed by the rapid freezing of supercooled water drops as they strike an exposed object. It is denser and harder than hoar frost, but lighter, softer, and less transparent than glaze.

ROLL CLOUD. (Sometimes called Rotor Cloud.) A turbulent altocumulus-type cloud formation found in the lee of some large mountain barriers, particularly in the Sierra Nevadas near Bishop, Calif. The air in the cloud rotates around an axis parallel to the range. Also sometimes refers to part of the cloud base along the leading edge of a cumulonimbus cloud; it is formed by rolling action in the wind shear region between cool downdrafts within the cloud and warm updrafts outside the cloud.

ST. ELMO'S FIRE. A luminous brush discharge of electricity from elevated objects, such as the masts and yardarms of ships, lightning rods, steeples, etc., occurring in stormy weather. Also called corposant.

SATURATED AIR. Air that contains the maximum amount of water vapor it can hold at a given pressure and temperature (relative humidity of 100 percent).

SHOWER. Precipitation from a convective cloud. Characterized by the suddenness with which it starts and stops, by the rapid changes of intensity, and usually by rapid changes in the appearance of the sky.

SLEET. Generally transparent, globular, solid grains of ice which have formed from the freezing of raindrops, or the refreezing of largely melted snowflakes when falling through a below-freezing layer of air near the Earth's surface.

SMOG. A natural fog contaminated by industrial pollutants; a mixture of smoke and fog.

SNOW. Precipitation in the form of white or translucent ice crystals, chiefly in complex branched hexagonal form and often clustered into snowflakes.

SOFT HAIL. White, opaque, round pellets of snow.

SOUNDING BALLOON. A free, unmanned balloon instrumented and/or observed for obtaining a sounding of the atmosphere.

SOURCE REGION. An extensive area of the earth's surface characterized by relatively uniform surface conditions, where air masses remain long enough to take on characteristic temperature and moisture properties imparted by that surface.

SQUALL. 1. A strong wind characterized by a sudden onset, a usual duration of several minutes, and a rather sudden decrease. 2. A severe local storm considered as a whole; that is, wind, cloud mass and (if any) precipitation, thunder, and lightning.

SQUALL LINE. Any nonfrontal line or narrow band of active thunderstorms (with or without squalls); a mature instability line.

STABILITY. A state in which the vertical distribution of temperature is such that an air particle will resist displacement from its level.

STATIC. In general, any radio interference detectable as noise in the audio stage. At broadcast frequencies, most naturally induced static is caused by nonperiodic electromagnetic radiation emitted by lightning discharges acting as huge antennae; it is also known as atmospherics. Aircraft radio communication is often hindered by *precipitation static* due to discharges from the aircraft surfaces following self-generated electrification.

STORM. A marked disturbance in the normal state of the atmosphere. The term has various applications, according to the context. It is most often applied to a disturbance in which strong wind is the most prominent characteristic. It is also used for other types of disturbances, including thunderstorms, rainstorms, snowstorms, hailstorms, duststorms, sandstorms, magnetic storms, etc.

STRATIFORM. Descriptive of clouds which are arranged in horizontal layers or sheets.

STRATOCUMULUS. A form of low cloud.

STRATOSPHERE. The layer of the atmosphere between the troposphere and the mesosphere where the air is usually stable (in the mean, the temperature within the layer increases with elevation).

STRATUS. A form of low cloud.

SUBLIMATION. Process by which a gas is changed to a solid or a solid to a gas without going through the liquid state.

SUBSIDENCE. An extensive sinking motion of air, most frequently occurring in polar highs. The subsiding air is warmed by compression and becomes more stable.

SYNOPTIC CHART. A weather chart describing the state of the atmosphere over a large area at a given moment.

SYNOPTIC METEOROLOGY. The branch of meteorology that deals with the analysis of weather observations made simultaneously at a number of points in the atmosphere (at the ground or aloft) over the whole or a part of the Earth, and the application of the analysis to weather forecasting and other problems.

TEMPERATURE. A measure of the degree of hotness or coldness of a substance.

THERMOGRAPH. A self-registering thermometer.

THERMOMETER. An instrument for measuring temperature; in meteorology, generally the temperature of the air.

THUNDER. The sound emitted by rapidly expanding gases along the channel of a lightning discharge.

THUNDERSTORM. A storm, invariably produced by a cumulonimbus cloud, and always accompanied by lightning and thunder; usually attended by strong wind gusts, heavy rain, and sometimes hail. It is usually of short duration, seldom over 2 hours for any one storm.

TORNADO. A violently rotating column of air attended by a funnel-shaped or tubular cloud hanging beneath a cumulonimbus cloud.

TRADE WINDS. Two belts of winds, one on either side of the equatorial doldrums, where the winds blow almost constantly from easterly quadrants.

TRAJECTORY. The path traced out by a small volume of air in its movement over the Earth's surface.

TRANSITION ZONE. The relatively narrow region occupied by a front. The meteorological properties in this zone exhibit large variations over a short distance and possess values intermediate between the characteristics of the air masses on either side of the zone.

TROPICAL DISTURBANCE. The name used by the Weather Bureau for a cyclonic wind system of the Tropics that is not known to have sufficient force to justify the use of the words "storm" or "hurricane."

TROPICAL AIR. Warm air having its source in the low latitudes, chiefly in the regions of the subtropical high pressure systems.

TROPOPAUSE. The boundary between the troposphere and stratosphere, usually characterized by an abrupt change of lapse rate.

TROPOSPHERE. The lower region of the atmosphere, from the ground to the tropopause. The average condition is typified by more or less regular decrease of temperature with increasing altitude; the portion of the atmosphere where the majority of vertical currents, appreciable water vapor content, and weather exist.

TROUGH. An elongated area of low atmospheric pressure, usually extending from the center of a low pressure system.

TURBULENCE. Irregular motion of the atmosphere produced when air flows over a comparatively uneven surface, such as the surface of the earth, or when two currents of air flow past or over each other in different directions or at different speeds.

TWILIGHT. Astronomical twilight is the interval between sunrise or sunset and the total darkness of night. Civil twilight is the period of time before sunrise and after sunset during which there is enough daylight for ordinary outdoor occupations.

TYPHOON. A severe tropical cyclone in the western Pacific.

VANE. A device that shows which way the wind blows; also called weather vane or wind vane.

VAPOR PRESSURE. The partial pressure exerted by water in the atmosphere.

VEER. Of the wind, to shift in a clockwise direction; opposite of "back." In scientific practice, this definition now applies to both hemispheres.

VIRGA. Wisps or streaks of water or ice particles falling out of a cloud but evaporating before reaching the earth's surface.

VISIBILITY. The greatest distance that prominent objects can be seen and identified by unaided, normal eyes.

WARM FRONT. The discontinuity at the forward edge of an advancing current of relatively warm air which is displacing a retreating colder air mass.

WARM SECTOR. The warm air area bounded by the cold and warm fronts of a wave cyclone.

WATERSPOUT. A tornado occurring over water; rarely, a lesser whirlwind over water, comparable in intensity to a dust devil over land.

WEATHER. The short-term variations of the atmosphere in terms of temperature, pressure, wind, moisture, cloudiness, precipitation, and visibility.

WET-BULB POTENTIAL TEMPERATURE. The temperature an air parcel would have if cooled from its initial state adiabatically to saturation, and thence brought moist adiabatically to the 1,000-millibar level. This temperature is conservative with respect to reversible adiabatic changes.

WIND. The horizontal movement of air relative to the surface of the earth.

APPENDIX I. SAMPLE SCRIPT

CONTINUOUS TRANSCRIBED WEATHER BROADCAST

(Also Used for PATWAS at Some Places)

AVIATION WEATHER FORECAST PREPARED AT 0930Z. 0430EST.

FLGT PRECAUTION IS RECOMMENDED OVR ALL RTES OUT OF DCA DUE TO TURBC, ICG, AND LOW CIGS AND VSBYS.

A LOW OVR SRN DEL WL MOV NNE AT 30 KT.

IN THE DCA AREA AND ALG RTES TO RDU AND ORF, CIGS 1 THSD FT VSBY GENLY 2 MI TO 4 MI IN LGT SNW AND SLT, FQTLY LWRG TO CIGS 5 HND FT AND VSBYS 1 MI THIS MRNG. CONDS WL IPV SLOLY TO ABT 25 HND FT AND 5 MI LATE THIS MRNG IN THE RDU AND ORF AREAS, WITH THE IPVG TREND PROGG SLOLY NWD DURG THE AFTN.

ON THE RTES TO TYS, PIT AND NEW YORK CITY, CIGS GENLY BLO 1 THSD FT, VSBYS LESS THAN 2 MI IN SNW. LTL OR NO IPVMT ALG THESE RTES EXPCD TDA.

THERE WL BE HVY ICGIC BLO 12 THSD FT IN THE DCA AREA AND ON THE RTES TO TYS, PIT AND NEW YORK CITY, AND MDT ICG BLO 10 THSD FT ON THE RTES TO ORF AND RDU. THERE WL BE MDT TURBC BLO 10 THSD FT OVR ALL RTES OUT OF DCA BUT OCNLY SVR TURBC IN THE VCNTY OF THE LOW PRES CNTR AND OVR THE MTNS TO PIT AND TYS.

WINDS ALOFT:

IN THE DCA, RDU AND ORF AREAS WNDS WL BE N 35 KT BLO 10 THSD FT, SHFTG GRDLY TO NNW BY EARLY AFTN. WNDS AT 10 THSD FT WL BE SSW 30 KT.

WNDS ALF IN THE NEW YORK CITY AREA BLO 8 THSD FT WL BE ENE 50 KT INCRG TO 65 KT WITH STG WND SHEARS. WNDS AT 8 AND 10 THSD FT WL BE SE 45 KT.

WNDS ALF OVR PIT BLO 10 THSD FT WL BE NNE 30 TO 40 KT CHGG GRDLY TO NNW. WNDS AT 10 THSD FT LGT VRBL, BCMG W 15 KT EARLY AFTN.

APPENDIX II. FREQUENTLY USED WORD CONTRACTIONS

A

ABT
ABV
level AGL
evel ASL
ACRS
ACTG
ACTV
ADVN
ADZ
ADVY
AFCT
AFT
AFDK
AFTN
AGN
AHD
ACFT
AMS
ARPT
AWY
ALF
ALG
ALTN
ALT
AMT
ANLYS
APCH
ARND
SFERICS
AVG

B

BCKG
BCM
BFR
BFDK
BGN
BHND
BLO
BNTH
BTR
BTN
BYD
BLZD
BDR
BNDRY
BRK
BRF

broken BRKN
build BLD

C

ceiling CIG
center CNTR
central CNTRL
change CHG
clear CLR
clear air turbulence CAT
clear or scattered clouds and visibility greater than 10 miles CAVU
cloud CLD
coast CST
condition COND
confine CFN
considerable CSDRBL
continue CONT
cover CVR

D

daybreak DABRK
daylight DALGT
decrease DCR
deep DP
deepening DPNG
degree DEG
delay DLA
dense DNS
develop DVLP
diffuse DFUS
diminish DMSH
dissipate DSIPT
distant DSNT
district DIST
ditto DO
downslope DNSLP
drift DRFT
drizzle DRZL
during DURG

E

elsewhere ELSW
ending ENDG
entire ENTR
evening EVE
except EXCP
expect EXPC
extensive EXTSV
extreme EXTRM

F

falling .... FLG
feet; foot; Fort .... FT
filling .... FILG
flurry .... FLRY
follow .... FLW
forecast .... FCST
forenoon .... FORNN
forward .... FWD
freeze .... FRZ
frequent .... FQT
from .... FM
frontal passage .... FROPA
frontal surface .... FROSFC
frost .... FRST
frozen .... FRZN
further; farther .... FTHR

G

general .... GEN
gradual .... GRDL
ground .... GND
ground fog .... GNDFG

H

hailstones .... HLSTO
half .... HLF
hear, here, hour .... HR
heavy .... HVY
height .... HGT
high .... HI
however .... HWVR
hundred .... HND
hurricane .... HURCN

I

icing .... ICG
icing in clouds .... ICGIC
icing in precipitation .... ICGIP
icing in clouds, in precipitation .... ICGICIP
immediate .... IMDT
important .... IMPT
improve .... IPV
increase .... INCR
indefinite .... INDEF
indicate .... INDC
information .... INFO
intense .... INTS
intensify .... INTSFY
interior .... INTR
intermittent .... INTMT
isolated .... ISOLD

J

jet stream .... JTSTR

K

knot or knots .... KT

L

later .... LTR
layer .... LYR
level ....
light ....
likely ....
limit ....
little ....
little change ....
local ....
lower ....

M

maritime ....
maximum ....
mean sea level ....
middle ....
midnight ....
mile or miles ....
minimum ....
mixed ....
moderate ....
morning ....
mountain ....
move ....

N

nautical mile or miles ....
night ....
numerous ....

O

obscure ....
observe ....
occasional ....
occlude ....
occluded front ....
occlusion ....
occur ....
off shore ....
on shore ....
other ....
outlook ....
over ....
overcast ....
overrun ....

P

partly ....
passing, passage ....
period ....
persist ....
portion ....
position ....
possible ....
precipitation ....
prevail ....
prognostic; prognosis, progress ....

R

ragged ....
rapid ....
reach ....
region ....

remain	RMN
repeat	RPT
restrict	RESTR
retard	RTRD
return	RTRN
ridge	RDG
rising	RSG
rough	RUF
route	RTE

S

scattered	SCTD
second; section	SEC
sector	SCTR
several	SVRL
severe	SVR
shallow	SHLW
shift	SHFT
shower	SHWR
sleet	SLT
slight	SLGT
slope	SLP
slow	SLO
small	SML
smoke	SMK
smooth	SMTH
snow	SNW
solid	SLD
somewhat	SMWHT
spread	SPRD
squall	SQAL
squall line	SQLN
stable	STBL
steady	STDY
storm	STM
strong	STG
surface	SFC
system	SYS

T

temperature	TEMP
temporary	TMPRY
tendency	TNDCY
terminal	TRML
terrain	TRRN
thereafter	THRFTR
thick	THK
thin	THN
thousand	THSD
through	THRU
throughout	THRUT
thunder	THDR
thundershower	TSHWR
thunderstorm	TSTM
today	TDA
tomorrow	TMW
tonight	TNGT
top of overcast	TOVC
topping	TPG
toward	TWD
trough	TROF
turbulence	TURBC

U

unrestricted	UNRSTD
unstable	UNSTBL
until	TIL
upper	UPR
upslope	UPSLP

V

valley	VLY
variable	VRBL
veer	VR
visibility	VSBY

W

warm	WRM
wave	WV
weak	WK
weaken	WKN
weather	WX or WEA
widely	WDLY
will	WL
wind	WND

APPENDIX III. ABBREVIATIONS AND SYMBOLS USED ON PROGNOSTIC SIGNIFICANT WEATHER CHARTS

AC	Altocumulus
AS	Altostratus
CC	Cirrocumulus
CI	Cirrus
CS	Cirrostratus
CB	Cumulonimbus
CU	Cumulus
NS	Nimbostratus
SC	Stratocumulus
ST	Stratus
CAT	Clear Air Turbulence
FRQ	Frequent
GRADU	Gradually, Gradual
LYR	Layered, Layers
TEMPO	Temporary, Temporarily
OCNL	Occasional, Occasionally
TURB	Turbulence


Moderate turbulence.


Severe turbulence.


Moderate icing.


Heavy icing.

$\frac{140\text{-}150}{80\text{-}100}$ Bases and tops of significant weather, in hundreds of feet (cloud layer, turbulence, icing, etc.)


Scalloped line depicting an area of significant weather. Scallop "arrow-points" point toward the significant weather.

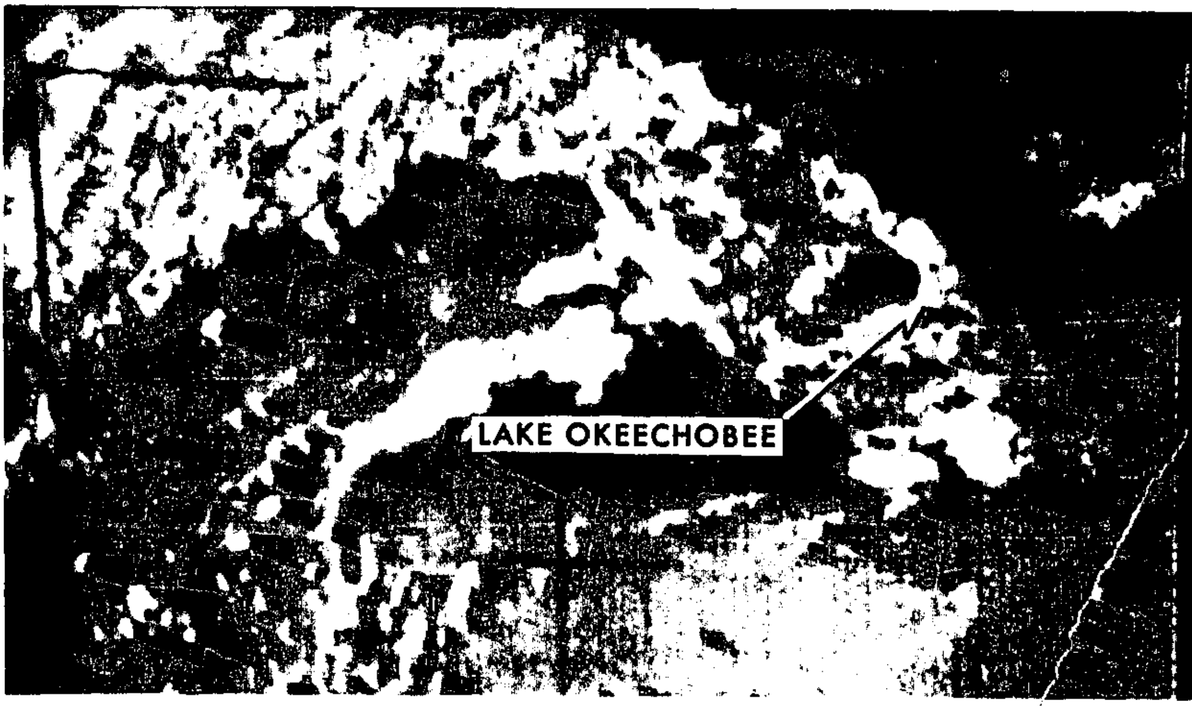

Thunderstorm.

APPENDIX IV. PHOTOGRAPHS OF CLOUDS TAKEN FROM HIGH ALTITUDES

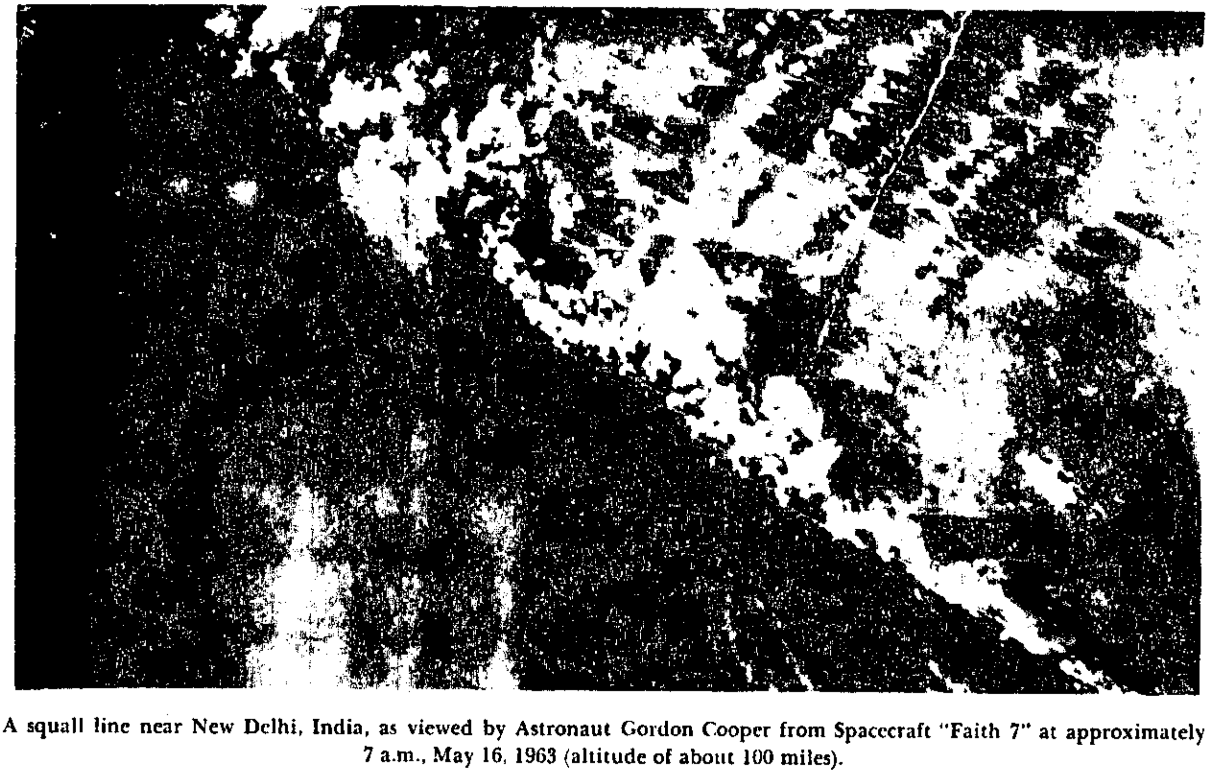
A view of clouds over Lake Okeechobee, Fla., from an aircraft at 27,000 feet, August 16, 1957 (courtesy Dr. R. Cunningham).

Cloud patterns over southern Florida, January 31, 1961, Mercury-Redstone launch vehicle No. 2, approximately 75 miles above the Earth. (Note Lake Okeechobee in the right portion of the photograph.)

APPENDIX IV. (Cont'd)

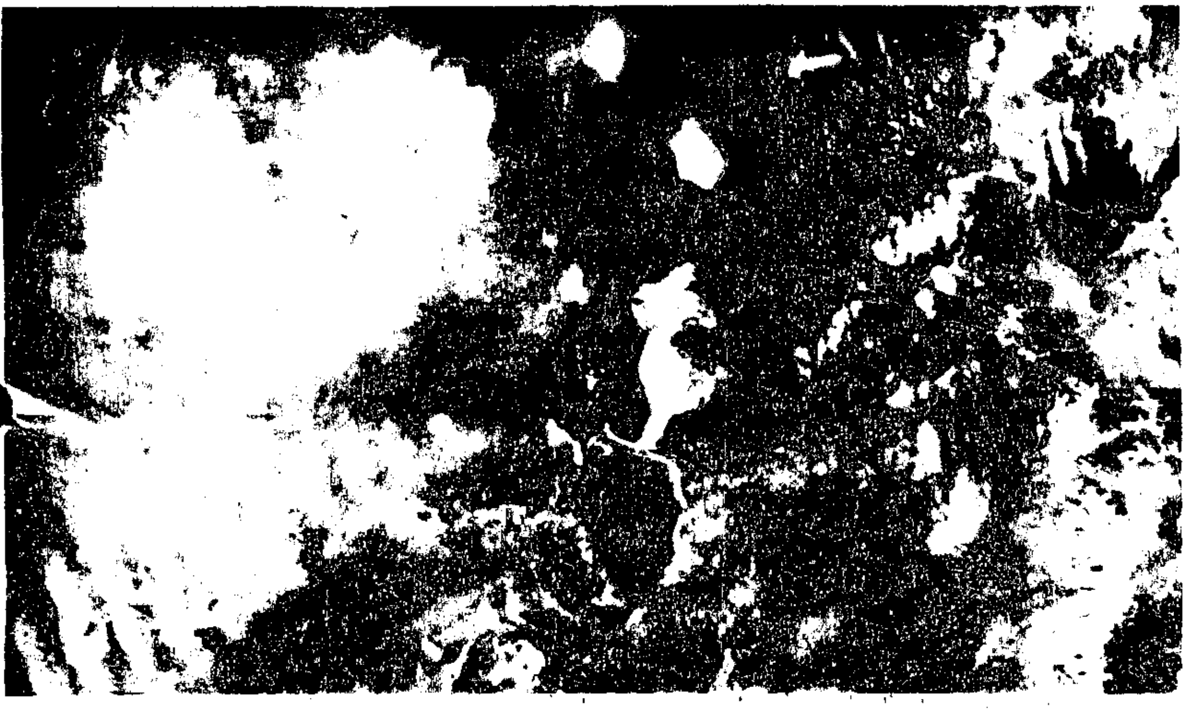


TIROS III (weather satellite) photograph showing cloud patterns over Florida and a squall line off the Florida coast and over the eastern Gulf of Mexico, from an altitude of approximately 410 miles. (Note the size of Lake Okeechobee as seen from this altitude.)



A squall line near New Delhi, India, as viewed by Astronaut Gordon Cooper from Spacecraft "Faith 7" at approximately 7 a.m., May 16, 1963 (altitude of about 100 miles).

APPENDIX IV. (Cont'd)

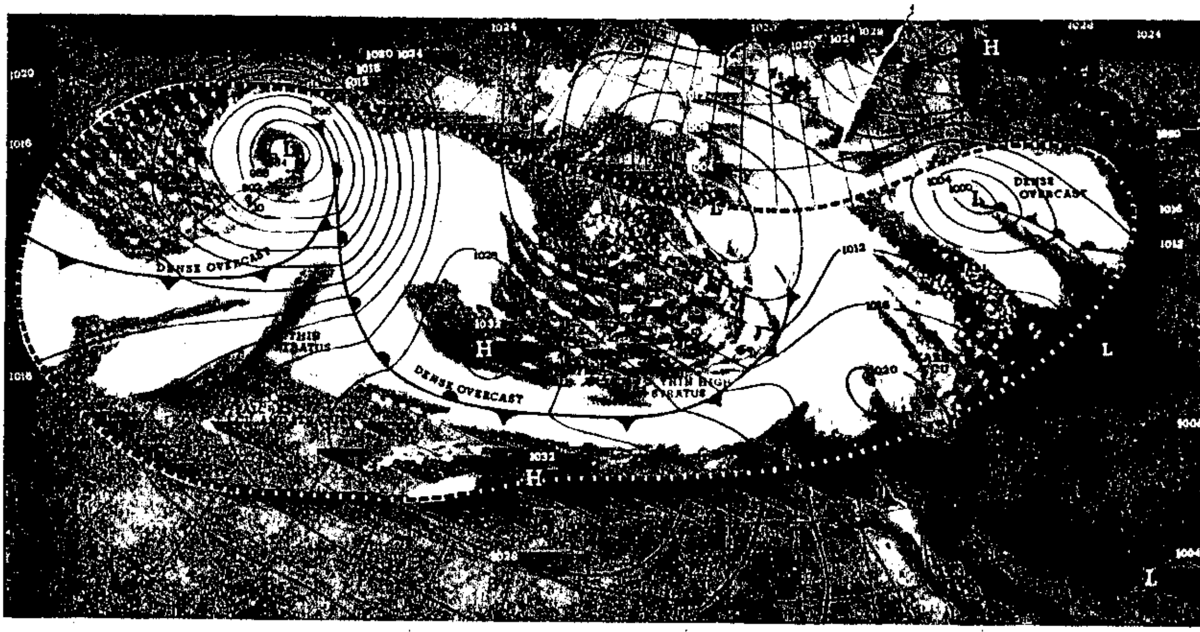


A series of mountain wave clouds (left portion of photograph) over the Tibetan Plateau (near latitude 31° No., longitude 85° E.) as viewed by Astronaut Gordon Cooper from spacecraft "Faith 7" at approximately 8 a.m., May 16, 1963. (Note the mountain ranges covered with snow in the right portion of the photograph, the ice covered lakes, and the clear lakes.)

TIROS V photograph of typhoon "Ruth" at latitude 31° N., longitude 141° E., August 18,1962.

APPENDIX IV. (Cont'd)

TIROS III photograph of the cloud pattern associated with an occluded cyclone centered at latitude 51° N., longitude 24° W., August 28, 1961.



Storm family over the North Pacific Ocean with TIROS cloud pictures superimposed on a conventional surface weather chart, May 20, 1960 (prepared by V. J. Oliver, U.S. Weather Bureau).

INDEX

T

023 SA23212100
DIA 15⦶M30⊕1/2VRW–F 152/68/60/3018G30/996/VR28 WSHFT 1548E/
⊕65/⊕V⦷ RB05 DRK NW VSBY 1/4V3/4 →DIA 9/5 QAPES ↘9/1

Symbol	Item	Interpretation	Translation
		GROUP I. 023 SA23212100	
023	Service A circuit identification.	The last 3 digits of a circuit number containing a total of 4 digits.	Service A circuit number 8023 (The primary use of this first number group is as a guide to the communicator for the distribution to be made of the material).
SA	Traffic designator........	Used to distinguish the material from other weather traffic on the circuit.	Hourly aviation collection with the specific meaning of *Aviation Sequence*.
23	Service A circuit identification.	The last 2 digits of a circuit number containing a total of 4 digits.	Service A circuit number 8023 (Repeated primarily to identify the circuit for the user of the reports).
21	Date	The day of the month........................	21st day of the month.
2100	Time of observation.....	Time of observation on the 24-hour clock in Greenwich mean time. To convert to local time, subtract 5 hours for eastern standard time, 6 hours for central, 7 hours for mountain, and 8 hours for Pacific.	4 p.m., eastern standard time.
		GROUP II. DIA. 15⦶M30⊕1/2VRW–F	
DIA	Station designator........	A 3 letter group in the United States identifying the station from which the report is sent. An attempt is made to assign designators that suggest the name of the sending station. Some examples are Oklahoma City (OKC), Tulsa (TUL), Richmond (RIC), Baltimore (BAL), San Francisco (SFO).	Dulles International Airport Washington, D.C.
15⦶M30⊕	Sky cover and ceiling.....	The figures represent the height above ground of the bases of the cloud layers in hundreds of feet. The heights refer to the sky cover symbols following the figures. ○ = Clear: Less than 0.1 sky cover ⦶ = Scattered: 0.1 to 0.5 sky cover ⦷ = Broken: 0.6 to 0.9 sky cover (constitutes a ceiling unless preceded by –) ⊕ = Overcast: More than 0.9 sky cover (constitutes a ceiling unless preceded by –) – = Thin (When prefixed to the above symbols)	Scattered clouds at 1,500 feet; overcast ceiling measured at 3,000 feet.

Symbol	Item	Interpretation	Translation
		GROUP II. **DIA. 15⌽M30⊕1/2VRW–F** (Cont'd) –X = Partial Obscuration: 0.1 to less than 1.0 sky hidden by precipitation or obstruction to vision (bases at surface) X = Obscuration: 1.0 sky hidden by precipitation or obstruction to vision (bases at surface) (constitutes a ceiling) The ceiling figure will always be preceded by one of the following letters: E = estimated; M = measured; W = indefinite; B = balloon; A = reported by aircraft; R = radiosonde or radar; D = estimated height of cirriform clouds U = cirriform ceiling height unknown. When cirriform clouds do not constitute a ceiling and the height is unknown, the slant bar (/) is used before the sky cover symbol. If the ceiling is below 3,000 feet and is variable, the ceiling symbol will be followed by the letter "V," and in the remarks the range of height will be indicated.	
1/2V	Visibility	Figures represent miles and fractions of miles. Followed by "V" if less than 3 miles and variable. If the visibility is 6 miles or less, the reason is always given under "Precipitation" or "Obstruction to vision."	Visibility ½ mile, variable.
RW-	Precipitation, thunderstorm, or tornado.	Weather Symbols A = hAil; L = drizzLe AP = small hail; R = Rain E = slEet; RW = Rain shoWers EW = slEet shoWers; S = Snow IC = Ice Crystals; SG = Snow Grains SP = Snow Pellets; SW = Snow shoWers T = Thunderstorm; ZL = freeZing drizzLe ZR = freeZing Rain (Tornado is always spelled out) Intensities Are Indicated Thusly: With the exceptions of A, AP, and IC, for which no intensity symbols are used, and for T, for which no "–" is used ("T" indicates a thunderstorm of moderate intensity or less), intensities are denoted by the following symbols: – – Very Light; (no symbol) Moderate – Light; + Heavy	Light rain shower.

Symbol	Item	Interpretation	Translation
		GROUP II. DIA. 15⦶M30⊕1/2VRW–F (Cont'd)	
F	Obstructions to vision....	*Obstruction to Vision Symbols* D = Dust F = Fog GF = Ground Fog K = smoKe BD = Blowing Dust BN = Blowing saNd BS = Blowing Snow BY = Blowing sprаY H = Haze IF = Ice Fog	Fog.
		GROUP III. 152/68/60/3018G30/996/	
		Most of the items in this group are separated by diagonal lines (/).	
152/	Pressure	Stated in millibars and tenths of millibars (omitting initial number "9" or "10").	Pressure 1015.2 millibars.
68/	Temperature	In degrees Fahrenheit	Temperature 68° F.
60/	Dew Point..................	In degrees Fahrenheit	Dew point 60° F.
30	Wind direction (direction from which the wind is blowing).	To the nearest 10 degrees starting at true north and moving clockwise through east and west, with true north reported as 360 degrees. 2 digits are transmitted omitting the final zero; that is, 01 is used to represent 10 degrees; 12, 120 degrees; 28, 280 degrees; etc. A calm wind is reported as a direction of 00.	Wind blowing from 300°.
18	Wind speed..............	Indicated in knots to the nearest knot. It is an average speed for a period of time, usually one minute. If the speed is estimated, the letter *E* will follow the value. If the wind is calm, the speed will be reported as 00.	Wind speed 18 knots.
G30/	Gustiness	Peak gust speed observed during the last 15 minutes prior to the time of observation. The letter *Q* in place of the *G* would indicate that squalls are present, followed by the peak speed in squalls during the same time interval used for gusts.	Wind gusts to 30 knots.
996/	Altimeter setting.........	Atmospheric pressure in inches and hundredths of inches of mercury for the setting of aircraft altimeters. Given in three figures, omitting the initial number "2" of "3." A number beginning with 5 or higher presupposes an initial 2; a number beginning with 4 or lower presupposes an initial 3 (993 = 29.93 inches, 002 = 30.02 inches, etc.).	Altimeter should be set to 29.96 inches.

Symbol	Item	Interpretation	Translation
		GROUP IV. **VR28 WSHFT 1548E/⊕65/⊕V⦶** **RBO5 DRK NW VSBY 1/4V3/4** This is the *remarks* section. Individual items are separated by diagonal lines (/) when they otherwise may be confused with one another.	
VR28	Remarks	The visual range down the instrument runway in hundreds of feet. For airports with multiple instrument runways and visual range measuring systems, VR22 would be a representative value obtained by averaging the visual ranges of all systems. If the visual range varies considerably from one runway to another, it is indicated separately with each runway identified. For example "VR30 R18VR20 R10VR40" would be interpreted as "representative (average) visual range 3,000 feet; runway 18, visual range 2,000 feet; runway 10, visual range 4,000 feet."	Runway visual range 2,800 feet.
WSHFT 1548E/	Remarks	WSHFT is used to indicate that the wind direction has shifted; it is followed by the local standard time on the 24-hour clock that the wind shift occurred.	The wind direction shifted at 3:48 p.m., eastern standard time.
⊕65/	Remarks	Heights (above mean sea level) in hundreds of feet of bases and/or tops of sky-cover layers not visible at the station.	Top of overcast is 6,500 feet.
⊕V⦶	Remarks	Remarks pertaining to coded elements reported in a preceding section.	The cloud layer based at 3,000 feet with tops at 6,500 feet is variable from overcast to broken.
RBO5	Remarks	Another remark relating to a coded element reported in a preceding section. This particular remark is in reference to the rain shower, meaning rain began at five minutes past the hour preceding the time of this observation. If rain had been reported on the last hourly report, but was no longer falling at the time of this observation, the remarks section would include the time that the rain (or other type of weather) ended by giving the letters RE, followed by the number of minutes after the last hourly report that the rain ended.	Rain began at 3:05 p.m., eastern standard time.
DRK NW	Remarks	An additional remark relative to the total weather picture in contractions of English words.	Dark to the northwest.
VSBY 1/4V3/4	Remarks	A remark relating to the prevailing visibility reported in Group I., giving the range in which the visibility is variable.	Visibility variable between ¼ and ¾ of a mile.

Symbol	Item	Interpretation	Translation
		GROUP V. →DIA 9/5 QAPES ↘9/1 When included, this section contains Notice to Airmen Information (NOTAMS) and is appended to the Aviation Weather Report following the last remark. Instructions for interpreting NOTAMS is usually available at weather briefing offices and may be obtained through reference to the FAA Air Traffic Service Handbook, Communications Procedures, AT P 7300.1.	
→	NOTAM group..........	Formerly an arrow denoting a wind from the west, this arrow is now used in connection with the automatic processing of NOTAMS and has no significance to the pilot.	
DIA	NOTAM group..........	Repeat of the station identifier given at the beginning of the Aviation Weather Report.	The Notice to Airmen Information which follows applies to Dulles International Airport, Washington, D.C.
9/5	NOTAM group..........	The first digit designates the month of the year. The digit following the "/" indicates the NOTAM number. NOTAMS are numbered serially for the month, beginning with "1" for the first NOTAM. No arrow preceding this item of the NOTAM group indicates that is the first time that this NOTAM has appeared on the circuit.	This is the 5th NOTAM during the month of September which has been issued for Dulles International Airport.
QAPES	NOTAM group..........	This is the substance of the NOTAM, using the "Q" codes which have been employed for many years.	VOR and associated voice communications out of service.
↘	NOTAM group..........	Current NOTAM indicator preceding the serial number of a previously transmitted NOTAM to indicate that it is still current.	Following is the serial number of a NOTAM for DIA which is still valid, but was transmitted earlier, and its contents will not be repeated in this report.
9/1	NOTAM group..........	These numbers are interpreted in the same manner as those preceding "QAPES" in this example.	The first NOTAM issued for DIA in the 9th month is still current. (The absence of 9/2, 9/3, and 9/4 indicates that those NOTAMS have been canceled.)

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